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IPRINT Methods Monograph: Aiding Development of Manpower-Based tem Evaluation

an D. Kaplan
I.S. Army Research Institute

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Applications International Corporation

K. Walker, Cecil D. Johnson, and David L. Payne
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United States Army Research Institute
for the Behavioral and Social Sciences

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UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS --
2a. SECURITY CLASSIFICATION AUTHORITY -- 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE --	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) --	5. MONITORING ORGANIZATION REPORT NUMBER(S) ARI Technical Report 849
6a. NAME OF PERFORMING ORGANIZATION See list on page ii. 6b. OFFICE SYMBOL (If applicable) --	7a. NAME OF MONITORING ORGANIZATION U.S. Army Research Institute for the Behavioral and Social Sciences
6c. ADDRESS (City, State, and ZIP Code) See list on page ii.	7b. ADDRESS (City, State, and ZIP Code) 5001 Eisenhower Avenue Alexandria, VA 22333-5600
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Research Institute for the Behavioral and Social Sciences 8b. OFFICE SYMBOL (If applicable) PERI-SM	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER MDA903-86-C-0412 MDA903-86-C-0414, MDA903-86-C-0416
8c. ADDRESS (City, State, and ZIP Code) 5001 Eisenhower Avenue Alexandria, VA 22333-5600	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62785A; PROJECT NO. 791; TASK NO. 121; WORK UNIT ACCESSION NO. C2

11. TITLE (Include Security Classification)
MANPRINT Methods Monograph: Aiding the Development of Manpower-Based System Evaluation

12. PERSONAL AUTHOR(S)
See list on page ii.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 86/11 TO 87/05	1989, June	

16. SUPPLEMENTARY NOTATION
Contracting Officer's Representative is Christine Hartel.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	MANPRINT; Manpower; Human factors; Jobs; Workload

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) is conducting a program to develop methods to successfully integrate available operations and maintenance personnel with weapon system hardware and software during the MANPRINT process. This monograph consists of three papers that describe alternative ways to determine the operations and maintenance manpower required by a weapon system design on a per system basis.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Jonathan D. Kaplan	22b. TELEPHONE (Include Area Code) (202) 274-8923	22c. OFFICE SYMBOL PERI-SM

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

ARI Technical Report 849

6a. NAME OF PERFORMINING ORGANIZATION (Continued)

Dynamics Research Corp. (DRC)
Hay Systems, Inc.
MicroAnalysis and Design (MA&D)
Perceptronics, Inc.
Science Applications International Corp. (SAIC)

6b. ADDRESS (Continued)

DRC--Wilmington, MA
Hay Systems, Inc.--Washington, DC
MA&D--Boulder, CO
Perceptronics, Inc.--Woodland Hills, CA
SAIC--McLean, VA

12. PERSONAL AUTHORS (Continued)

Jonathan D. Kaplan (ARI, Editor)
Rick Archer, Ron Laughery, and Susan Dahl (MA&D)
Larry O'Brien (DRC)
Eleanor Criswell, Dennis Faust, and Mike Smith (SAIC)
Lanny K. Walker, Cecil D. Johnson, and David L. Payne (Hay Systems, Inc.)
Carl F. Asiala (Perceptronics, Inc.)

Technical Report 849

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Jonathan D. Kaplan
Editor, U.S. Army Research Institute

Rick Archer, Ron Laughery, and Susan Dahl
MicroAnalysis and Design

Larry O'Brien
Dynamics Research Corporation

Eleanor Criswell, Dennis Faust, and Mike Smith
Science Applications International Corporation

Lanny K. Walker, Cecil D. Johnson, and David L. Payne
Hay Systems, Inc.

Carl F. Asiala
Perceptronics, Inc.

Manned Systems Group
John F. Hayes, Chief

Systems Research Laboratory
Robin L. Keesee, Director

U.S. Army Research Institute for the Behavioral and Social Sciences
5001 Eisenhower Avenue, Alexandria, Virginia 22333-5600

Office, Deputy Chief of Staff for Personnel
Department of the Army

June 1989

Army Project Number
2Q162722A791

Manpower, Personnel, and Training

FOREWORD

The U.S. Army Research Institute for the Behavioral and Social Sciences ~~(ARI)~~ is conducting a program to develop MANPRINT methods to successfully integrate Army personnel with weapon system hardware and software. As the first stage of this process, ARI defined requirements for six classes of methods and called for the development of alternative concepts for each class.

This monograph describes three alternative concepts for building a method to predict required operator and maintainer crew sizes for a system. The resulting crew sizes can be used to evaluate the manpower implications of a weapon system design and can serve as the basis of a cost-benefit analysis. These concepts will serve as the focus of current system building and may serve as a seedbed for the development of alternative systems.

EDGAR M. JOHNSON
Technical Director

MANPRINT METHODS MONOGRAPH: AIDING THE DEVELOPMENT OF MANPOWER-BASED SYSTEM EVALUATION

EXECUTIVE SUMMARY

The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) is conducting a program to develop methods to successfully integrate operations and maintenance personnel with weapon system hardware and software during the MANPRINT process. To do this, ARI defined requirements for six classes of methods. In the first phase of this effort, three alternative concepts were developed for each of the six classes of methods.

This monograph consists of three papers that describe alternative concepts for determining the operations and maintenance manpower required by a weapon system design on a per system basis.

Ultimately, the ARI study advisory group selected the concept proposed by MicroAnalysis & Design for implementation. However, each of the three concepts is the result of serious thinking about how to deal with manpower prediction. As such, all three concept papers may be of considerable value for research in this area.

MANPRINT METHODS MONOGRAPH: AIDING THE DEVELOPMENT OF MANPOWER-BASED SYSTEM EVALUATION

Jonathan D. Kaplan, Editor
U.S. Army Research Institute

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U.S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction of the Deputy Chief of Staff for Personnel

EDGAR M. JOHNSON
Technical Director

JON W. BLADES
COL, IN
Commanding

Research accomplished under contract
for the Department of the Army

MicroAnalysis and Design, Dynamics Research Corp., Science Applications International Corp., Hay Systems, Inc., and Perceptronics, Inc.

Technical review by

Christine R. Hartel
John E. Stewart

NOTICES

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MANPRINT METHODS MONOGRAPH: AIDING THE DEVELOPMENT OF MANPOWER-BASED SYSTEM EVALUATION

Introduction

The U.S. Army Research Institute (ARI) is conducting a research program to develop methods to aid in successfully integrating available operations and maintenance personnel with hardware and software as part of the general MANPRINT process. To do this, ARI defined and produced requirements for six classes of aiding methods. The first four of these methods will aid the integration process by developing information that will be used as system design constraints. This information will be used in requirements documents and will be provided to potential design organizations. The last two of these methods will aid the integration process by providing mechanisms to evaluate system designs.

This monograph consists of three papers on a common subject: How to determine the number of soldiers per system required by a design to reach criterion performance and availability. Each of these three papers presents a concept for building an aiding method for making these predictions. These methods would all be software based and provide aid without significantly raising their user's workload. All concepts were generated in response to the same Army requirement. To understand these concepts fully, one must first understand the context in which they were developed.

The Army acquires systems as mechanisms for obtaining needed performance. The hardware and software components of most Army systems are operated and maintained by soldiers. Therefore, soldiers are components of those systems. The performance and availability levels of systems are directly related to the performance of the trained soldiers who operate, maintain, and support their hardware and software.

The decision to move from system design to prototype hardware and software is a major one that commits the Army to considerable expense and eventually to battlefield risk. The hardware and software development community has demonstrated the ability to produce products that, in theory, are capable of very high levels of performance and system availability. The key words here are "in theory." In practice, these high levels are not often produced by operational Army personnel, although they are demonstrated by the development community. This gap between theoretical and operational performance and system availability often occurs because it is difficult for the Army to obtain adequate numbers of personnel who, following typical training, are capable of operating and maintaining equipment of suboptimal design to required levels. This being the case, the Army needs to be able to determine the numbers and

kinds of personnel required by design features to reach criterion performance and system availability prior to deciding to move from an existing initial design to the building of a prototype. The determination of the availability of the required numbers and kinds of personnel will allow the Army to engage in a rational evaluation of system designs.

The purpose of this specific aiding method is to evaluate designs by determining the jobs and the number of people per job required to operate and maintain the hardware and software as designed, so that the Army has a basis to determine manpower requirements and compare that to manpower availability. Jobs are defined as that cluster of described tasks which are to be performed by one individual in operating or maintaining system hardware.

The three concepts for this manpower-based evaluation aid were written by a collaboration of Micro Analysis & Design (MA&D) and the Dynamics Research Corporation (DRC), Science Applications International Corporation (SAIC) acting as a subcontractor to Applied Science Associates (ASA), and a collaboration of Hay Systems, Inc. and Perceptronics Inc. Eventually, ARI chose to complete the development of MA&D's concept. However, all three concepts have considerable merit and are quite diverse in approach.

The MA&D-DRC concept requires the development of three, simulation-based methods in one shell. One method determines the number of maintainers required to reach criterion sytem availability by simulating hardware breakdowns and maintenance task performance at the component level. The second and third methods attempt to determine the required number of operators or maintainers assuming either that the design can be altered to introduce additional personnel, or that workload can be optimized among a fixed number of personnel by reallocating tasks. The second method uses a simulation to compare time available to time required for each task of each job. The third method links a cognitive workload model to the time required model to provide a more detailed basis for creating new jobs or optimizing workload among existing jobs.

The SAIC concept is based upon providing a two-step task-clustering, precedence-network analysis aid. In the first of two steps, operator or maintainer tasks are clustered based on their association with system performance objectives that have been entered by the user. In the second step, unique jobs are created based on task clusters, sequences and times plus any job constraints entered by the user. These jobs fall into the categories of time-based,

output-based, and continuous monitoring-based. In general, the method attempts to create or optimize jobs by reallocating those tasks that can be performed in the least period of time.

The Hay-Perceptronics concept fundamentally is based upon clustering tasks into jobs according to a combination measure of their similarities and utilities (S/U). This is done within the context of a set of rules that determine the possibility of task performance for a given job using a given interface design. The S/U measure discussed in this approach is "competency." It is determined by comparing measures of the basic skills and capabilities that personnel must posses to perform tasks, and is derived from training data. Once tasks are clustered, the resulting jobs will be tested for workload using some form of network simulation.

As with all apparently simple ideas, complexity increases as one tries to visualize implementation. This can be seen in the necessity to answer the following two questions in any concept for evaluating designs on a manpower basis. (1) How would a manpower based evaluation aid deal with crew size prediction for operations versus maintenance crews? (2) How would such an evaluation aid deal with designs in which crew size is a function of specific interface design versus somewhat arbitrary function allocation? Inherent in the first question is the issue of whether individual maintenance task design should be optimized in the same manner as is typically given to operations tasks. Inherent in the second question is the issue of how to do a manpower-based analysis of a system in which the interface hardware design has been made for a specified number of people. The concepts presented here wrestle with such complexity with varying degrees of success. However, much is to be gained in the exercise and in the competition of ideas.

The three concept papers in this monograph have been paginated as E1, E2, and E3 to delineate them clearly.

MANPRINT METHODS MONOGRAPH:
AIDING THE DEVELOPMENT OF MANPOWER-BASED SYSTEM EVALUATION

MANPOWER DETERMINATION AID

Written by:

Rick Archer
Ron Laughery
Susan Dahl
MicroAnalysis and Design

Larry O'Brien
Dynamics Research Corporation

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MANPOWER DETERMINATION AID

SECTION 1 - INTRODUCTION

1.1 Objective of Paper

This concept paper describes the Micro Analysis and Design and Dynamic Research Corporation team's approach to the development of a Manpower Determination Aid (MDA). The purpose of the MDA will be to provide Army manpower analysts with a tool for evaluating manpower requirements for a given contractor design. There are three primary things that the MDA will produce, 1) job titles and descriptions, 2) allocations of tasks to jobs, and 3) the numbers of individuals for each job type required to support one system (e.g., a tank).

1.2 Overview of the Approach

We have split the MDA into two fairly distinct components, one for predicting manpower requirements for <u>operators</u> of systems and one for predicting manpower requirements for <u>maintainers</u> of systems. Both work in a conceptually similar manner, although the details of using each component are different. In fact, the operator prediction tool could also be applied to maintainers, however; in our concept we have chosen a simpler tool for the maintainer prediction tool.

Both operator and maintainer components require the development of a list of tasks which must be performed as well as relationships between frequency of task performance and specific mission scenarios. Then, based on a variety of potential starting points, operator and maintainer jobs are initially defined and tasks are allocated to these operator and maintainer jobs. This initial allocation of tasks to operators and maintainers represents the first "hypothesis" about how tasks should be allocated to jobs. Then, this hypothesis is tested against three types of constraints, 1) a workload constraint (i.e., can the operators and maintainers perform the tasks in the allotted time and still maintain a reasonable level of workload?), 2) performance constraints (i.e., can the operators meet system performance requirements and can maintainers meet system availability requirements?), and 3) supportability constraints (i.e., can the system design support the number of operators and maintainers).

The extent to which a given task allocation to jobs will satisfy workload and performance constraints are explored through the use of computer simulation. The heart of the MDA will be a set of tools which will permit rapid development, execution, and analysis of computer simulations to study workload and system

performance. The proposed concept builds off of existing easy-to-use simulation tools. The computer simulations will permit the evaluation of the extent to which a specific contractor design will violate either workload or performance constraints given the hypothesized allocation of tasks to jobs.

The supportability constraint will be studied in a more straightforward manner. It will involve the user of the MDA to review a series of questions relating to the allocation of tasks to jobs considering the specific contractor design.

The process of defining an acceptable allocation of tasks to jobs and the associated numbers of individuals for each job will be one of 1) develop a hypothesis, 2) using the MDA, test the hypothesis, and 3) if it does not satisfy all constraints, reallocate tasks to jobs or change the number and type of jobs, and 4) test this "new" hypothesis. Of course, the MDA will provide a number of diagnostic tools to assist the user of the MDA in identifying "better" allocations of tasks to jobs. The user of the MDA will proceed through this hypothesis testing process until either an alternative is found that satisfies all constraints or it becomes clear that no such alternative exists.

The workload portion of the MDA, which is used to predict the operator's jobs, also considers another type of constraint, the accessability constraint. In other words, the tool will aid the analyst in ensuring that no tasks are allocated to operators that involve controls or displays that he cannot reach or see.

The overall maintenance requirements are determined by computer simulation. Embedded in the maintenance component of the MDA will be a simulation model that will use Monte Carlo simulation techniques to aggregate the maintenance manpower requirements based on the maintenance requirements of the individual components.

The software that will be included in the maintenance component of the MDA will guide the analyst through the process of identifying and entering the tasks required to maintain each component in the proposed system, how frequently each task needs to be performed, and what kinds of maintainers are needed to perform those tasks. The software will also assist the Army analyst in defining mission scenarios that will determine 1) the usage rates for each component, and 2) the amount of time that is available for maintenance in different mission scenarios given system availability requirements.

The computer simulation model that is embedded within the maintenance component of the MDA will use the component maintenance requirements, usage rates, and the time that is allotted for maintenance during the simulation period to simulate the overall maintenance requirements of the proposed new system. The results of the simulation will give the Army analyst an indication of the different maintenance jobs that were required

during the analysis period, the tasks that were assigned to each maintenance job, the number of hours of maintenance that were required for each maintenance job, and the actual number of people that were required to maintain system availability for mission requirements and the percentage of time that number were needed.

Virtually the entire process of using the MDA will be automated. When using the MDA to define jobs, tasks per job, and numbers per job, the user will be provided with menus for filling in the necessary information. Also, a key part of the MDA will be a series of on-line libraries available to the user. In these libraries will be data on existing systems which the analyst may draw upon to establish initial job definitions, task analyses, task assignments to jobs, and task performance parameters required for the simulation. Additionally, there will be specific software to aid the user in the development of the above information should none of the data in the library be appropriate.

The underlying analytical techniques for both the operator and maintainer portions of the MDA are tried and tested. However, the MDA tools which are discussed in this paper will differ in that they will be orders of magnitude easier and faster to use than current tools. Furthermore, the "pieces"of the MDA have already been tested in other military environments by the authors of this paper. For the aforementioned reasons, it is safe to say that there is neither technical nor cost risk with the approach presented herein.

The approach to an MDA presented in this paper represents a practical, logically-based, quantitative approach to directly evaluating a system design with respect to the manpower required to operate and maintain that proposed system.

1.3 Organization of Paper

The remainder of this concept paper is organized into five sections. The section on product requirements includes the product's objectives, significant output, users, role in the acquisition process, assumptions, and the high-level functional requirements and constraints associated with it.

The next two sections describe the two modules that make up the MDA; the Workload Assessment Aid (WAA) and the Maintenance Manhour Analysis Aid. Each of these sections is organized into three sub-sections. The overview of each section discusses:

- the theory behind the approach used for the aid.
- the approach itself.
- the outputs of the aid.

- the automated components that make-up the aid.
- the approach for product development.

The second sub-section for each of the two modules contains a detailed discussion of the steps that an Army analyst will follow to use the aid. For each step we have included:

- the inputs that are required.
- the process that the analyst will follow.
- the outputs of the step.
- a discussion of user interface issues.

The third sub-section in each module section will contain a detailed discussion of the software elements that are included in that module.

The final section contains references that are used throughout the concept paper.

SECTION 2 - PRODUCT REQUIREMENTS

2.1 Objectives

The purpose of the Manpower Requirements Determination Aid (MDA) is to determine the quantitative manpower requirements for a specific contractor's design. The MDA will be used during the Proof-of-Principle Phase, after the contractor submits the initial designs, but before one design is chosen to develop into a prototype. The Manpower Determination Aid's output will be used with the output from Product 6. The combined output will help develop manpower, personnel, and training (MPT) alternatives that minimize personnel characteristics deficits. These deficits are discrepancies between the type and number of people required and the number of such people likely to be available when the system is fielded.

2.2 Major Output

The MDA will determine manpower requirements for each contractor design. These requirements will include: 1) the jobs associated with each design, 2) the tasks associated with each job, and 3) the number of operators or maintainers in each job. In addition to defining manpower requirements by job or duty position, the MDA will be capable of assigning each job to an MOS, and calculating total manpower requirements by military occupational specialty (MOS), skill level, major component item (for maintainers only), and maintenance level (for maintainers only).

In addition to producing manpower requirements estimates, the MDA will have the capability to estimate system availability, reliability, and operational effectiveness. We will compare these estimates with the requirements that the System Performance Requirements Estimation Aid (Product 1) identified during the Requirements Technology Base Activities Phase of the Materiel Acquisition Process (MAP). This comparison can identify shortfalls (discrepancies between requirements and estimates based on contractor design).

2.3 Role of Product Output in Acquisition Process

During the acquisition process, manpower requirements for an emerging system are described primarily in two documents. These documents are the basis-of-issue plan (BOIP) and the qualitative and quantitative personnel requirements information (QQPRI) documents. This section explains how these documents present quantitative manpower requirements, where the information comes from, and who is responsible for this information.

The MDA will be designed to provide <u>input</u> to these two documents.

BOIP

The BOIP:

> "States the number of new or improved items of equipment and personnel to be included in Tables of Organization and Equipment (TOE) Level 1 (100 percent wartime requirements), Tables of Distribution and Allowances (TDA), Joint Tables of Allowances (JTA), Additive Operational Projects (AOP), and TDA Augmentation to Modified Tables of Organization and Equipment (MTOE) when directed by HQDA." (Revised AR 71-2, Section 1-5)

The BOIP must justify the Manpower requirements it includes by clearly stating:

> "The rationale considered in determining the type and number of items and personnel needed to support the principal item (QQPRI, operator and maintainer decision). Personnel increases exceeding requirements document estimates will be justified or trade-off assessment completed." (Section 5-9)

The Deputy Chief of Staff for Operations and Plans (DCSOPS) is the Army staff proponent for the BOIP system.

QQPRI

The revised AR 71-2 describes:

> "The QQPRI...[as] a compilation of organizational, doctrinal, training, duty position, and personnel information. It is prepared for a new or improved item of equipment by the materiel developer in coordination with the combat and training developer...The QQPRI is used as follows:
>
> (1) To determine the need to establish or revise a Military Occupational Specialty (MOS), Specialty Skill Identifier (SSI), and civilian OPMCS.
>
> (2) To prepare plans to provide the personnel and training needed to operate, maintain, and transport the new or improved item of equipment.
>
> (3) As a source document for direct productive annual maintenance manhours (DPAMMH)."

Figure 1 presents the QQPRI format. One of the QQPRI's key components is the DPAMMH:

"[The] DPAMMH will be based on the empirical data or, as a minimum, estimated hours will be submitted and so identified for all developmental items of equipment or system. Hours will be expressed by MOS, SSI, and OPMCS for each category of maintenance. When LSA data or engineering estimates are sources for DPAMMH, the annual usage rate used in the computation should be provided. This annual usage rate should be a derivative of equipment mission profile found in the appropriate materiel need document." (Section 4.8)

According to AR 71-2, the QQPRI also presents:

"The number of direct operators needed to make up a crew or operate the system as a single shift and a listing of duty positions, by descriptive title, required for operation and maintenance of the equipment. [It also contains] a suggested placement of duty positions within a current, revised, or new commissioned officer SSI, or warrant officer or enlisted MOS, special qualification identifier (SQI), ASI, or civilian OPMCS.

A listing of the individual system unique duties and tasks to be performed in each of the above identified positions requiring new, revised, or current MOS, SSI and OPMCS. Other special characteristics (e.g., a certain height to operate equipment, a security clearance required to operate or maintain the equipment that is not normally required) will also be identified." (Section 4.8)

As the QQPRI format presented in Figure 1 indicates, "Materiel developers will identify LIN, nomenclature, description, levels of maintenance (UL, IDS, IGS, AVIM, AVUM), MOS, SSI, and civilian OPMCS."

TITLE: **The title of the QQPRI will identify the type of QQPRI, the title of the principal item, the LIN, PIP number, and the new equipment training plan (NETP number). This same title will be used on all correspondence forwarding the QQPRI through channels. Note: Once TRADOC assigns the BOIP number, the number(s) will be included in all subsequent correspondence.**

1. **REQUIREMENT INFORMATION:**

   a. Requirement or Procurement Directive:
   b. Type Classification (TC) date:
   c. First Unit Equipped date (FUED):
   d. Army Modernization Information Memorandum (AMIM) Number: (Note 1)

2. **DESCRIPTION AND DIRECT PRODUCTIVE ANNUAL MAINTENANCE MANHOURS (DPAMMH):** (Notes 2, 3, 4, and 5)

   a. Principal Item:
   b. Component Major Item:
   c. Total DPAMMH by MOS, SSI, or OPMCS for subparagraphs a and b above:
   d. Associated Support Items of Equipment (ASIOE):

3. **NUMBER DIRECT OPERATORS REQUIRED TO CREW OR OPERATE EQUIPMENT:**

4. **DUTY POSITIONS BY DESCRIPTIVE TITLE:**

5. **INDIVIDUAL UNIQUE DUTIES, TASKS, AND CHARACTERISTICS:** (Notes 6 and 7)

6. **NETP NUMBER AND NET TRAINING BASE REQUIREMENTS:** (Notes 1 and 8)

(Enclosures - Draft Job Specifications)

Note 1. Use "NA" for paragraphs 1d and 6 when not applicable.

Note 2. The format subparagraphs a through d above will appear on all QQPRI. This format is very flexible to use on the four subparagraphs (a-d) or can be expanded by using "high school outline" to accommodate major systems, or multiple LIN under each subparagraph (a, b, and d).

Note 3. Materiel developers will identify LIN, nomenclature, description, levels of maintenance (UL, IDS, IGS, AVIM, AVUM), MOS, SSI, and civilian OPMCS. Materiel developers will always provide DPAMMH for the principal LIN and the component major items whether they are type classified or not. Additionally, the materiel developers will provide DPAMMH for all ASIOE that have developmental items. For type classified ASIOE, the materiel developer will list the LIN and nomenclature only. DPAMMH will be based on the empirical data, or as a minimum, estimates will be submitted and so identified. DPAMMH should represent the maintenance burden generated by one item of equipment during one year. When LSA data or engineering estimates are sources for DPAMMH, the annual usage rate used in the computation should be provided. This annual usage rate should be derivation of equipment mission profile found in the appropriate materiel need document. Usage of "Note" to explain information or rationale is encouraged.

Note 4. Formatting for each LIN under the subparagraph a and b including the type of equipment is below. MCI will be subdivided by developmental item(s) and type classified item(s); show NSN or PN for all CMI.

Figure 1. QQPRI Format

LIN, Generic Nomenclature, Description (for TMDE start the description with the term "TMDE" and include Central TMDE Activity (CTA) approval number)

<u>MOS/SSI/OPMCS</u> <u>UL</u> <u>IDS</u> <u>IGS</u>

Note 5. Subparagraph c is to be calculated on the basis of one principal item and any CMI in required quantities. Formatting will be:

<u>MOS/SSI/OPMCS</u> <u>DPAMMH</u>

Note 6. Paragraph 5 above:

a. Do not include skills. The SGA determines the skill level.

b. Include MOSs that support the maintenance levels of all ASIOE.

c. For aviation equipment, include any ground maintenance that is not authorized in AVUM/AVIM, but are at the UL, IDS, and IGS level of maintenance.

Note 7. Paragraph 5 above:

a. If the duties and tasks listed in AR 611-101, AR 611-112, or AR 611-201 are adequate, use the following for each MOS or SSI:

FOR COMMISSIONED OFFICERS:

SSI. . . (indicate any SQI here) performs duties and tasks as listed in AR 611-101.

FOR WARRANT OFFICERS OR ENLISTED:

MOS. . . (indicate any ASI or SQI here) performs duties and tasks as listed in (AR 611-112, AR 611-201).

b. If the duties and tasks listed in AR 611-101, AR 611-112, AR 611-201 do not include the system unique duties, tasks, or characteristics, use the following for each MOS and SSI:

FOR COMMISSIONED OFFICERS:

SSI. . . (indicate any SQI here) . . . . (indicate system unique duties, tasks, characteristics). Other duties and tasks are listed in AR 611-101.

FOR WARRANT OFFICERS OR ENLISTED:

MOS. . . (indicate any ASI or SQI here). . . . (indicate system unique duties, tasks, characteristics). Other duties and tasks are listed in (AR 611-112 or AR 611-201).

c. If the duties and tasks in AR 611-101, AR 611-112 or AR 611-201 need to be revised, use the following for each MOS and SSI:

Figure 1. QQPRI Format (Continued)

FOR COMMISSIONED OFFICERS:

Revised SSI. . . (indicate any current or new SQI here). Draft proposed job specifications are attached at enclosure. . . . Other duties and tasks are listed in AR 611-101.

FOR WARRANT OFFICERS OR ENLISTED:

Revised MOS. . . (indicate any current or new ASI or SQI here). Draft proposed job specifications are attached at enclosure... . Other duties and tasks are listed in (AR 611-112, AR 611-201).

d. If a new MOS, SSI, ASI, or SQI will be required for AR 611-101, AR 611-112, or AR 611-201, use the following for each MOS and SSI:

FOR COMMISSIONED OFFICERS:

New SSI. . . (indicate any SSI here). Draft proposed job specifications are attached at enclosure. . .

FOR WARRANT OFFICERS AND ENLISTED:

New MOS. . . (indicate any ASI or SQI here). Draft proposed job specifications are attached at enclosure. . . .

Note 8. Provide the following for Paragraph 6:

a. NETP number (if none, so state).

b. UIC, quantity, LIN, nomenclature and justification for any NET Training Base requirements.

Figure 1. QQPRI Format (Continued)

The combat developer within the TRADOC proponent school has primary responsibility for developing the BOIP and QQPRI. The Program Manager within the Army Materiel Command (AMC) subordinate command provides input to the combat developer. DCSOPS processes and approves both the BOIP and QQPRI.

The latest version of AR 71-2 recognizes that the Army HARDMAN methodology, as the Army's current manpower determination aid, feeds the BOIP and QQPRI data. But AR 71-2 also leaves room for additional DCSPER-approved methodologies:

> "The results of hardware vs. manpower (HARDMAN) methodology or an approved DCSPER methodology will provide source data for the BOIP and QQPRI process." (Revised AR 71-2, 10 Oct. 1986, p. 10)

The MDA will probably become one of the additional methodologies cited in AR 71-2. By systematically assessing workload, the MDA will provide more accurate estimates of manpower requirements, particularly operator requirements.

Manpower Assessment in Support of Requirements Documents

The Letter of Agreement (LOA) and Required Operational Capability (ROC) both have sections that require reporting the results of a "manpower/force structure assessment." TRADOC/AMC PAM 70-2 describes this assessment as follows:

> "Manpower/Force Structure Assessment. Estimate manpower requirements per system, using unit, and total Army by component (Active, ARNG, USAR). Identify manpower savings resulting from replaced systems, if any. Include a statement to require an assessment of alternatives to reduce manpower requirements and an assessment of force structure implications resulting from system inclusion in the total force by component.
>
> If the force structure assessment exceeds current programmed force structure levels, then identification of force structure tradeoffs within mission area or mission elements is required. Tradeoffs analysis are addressed to the degree necessary to bring the force structure assessment within current programming levels, if possible. The personnel support package will be tested during OT II."

Manpower Requirements Determination in MANPRINT

Currently, there are two major sources of MANPRINT regulatory information. The first is AR-602-2, MANPRINT. The second is the Draft chapter on MANPRINT that will be included in the revised TRADOC/AMC PAM 70-2, Materiel Acquisition Handbook (hereafter referred to as the revised TRADOC/AMC PAM 70-2).

According to AR 602-2 (p. 27), "MANPRINT data to support the BOIP and QQPRI shall be developed during the Proof-of-Principle Phase of the MAP. This regulation also cites HARDMAN and (ECA) as two techniques that can be used "as inputs to the BOIP process" (p. 27).

The revised AR 70-2 identifies the following activities related to Manpower Requirements Determination Aid (p. 11.44 to 11.76):

Requirements and Technology Base Activities Phase

- Initiate HARDMAN and ECA early in this phase

Proof-of-Principle Phase

- Conduct HARDMAN
- Develop input to BOIP and QQPRI
- Provide input to ROC on the "number of operators, maintainers, and repairers the new equipment requires in each unit." AR 70-2 describes the manpower requirements information to be included in the ROC.

The revised version of TRADOC/AMC PAM 70-2 provides additional information in manpower determination related to MANPRINT. According to this regulation, the DCD - Materiel and Logistics System Division, with input from DOTD, ARI, and AMC should provide input to Required Operational Capability (ROC). To provide this input this organization should conduct a force structure analysis using information developed in the organizational plan. The analysis would determine the number of pieces of new equipment going into each type unit and the number of operators, maintainers and repairers the new equipment requires in each unit. They should also identify proposed bill-payers to ensure a zero growth in the force structure, if the number required for the new system exceeds the number available from the displaced system.

Table 1 provides examples of the manpower and personnel information to be included in the ROC.

Table 1

Example of Manpower and Personnel Information to be Included in ROC.

<u>This is an example of Manpower/Force Structure Assessment to be included in the ROC, para 5a:</u>

"a. Manpower/Force Structure assessment. The manpower force structure indicates that when the system is fully fielded in accordance with current plans, it will generate the following requirements:

	Crew Per System	Crew System & Support Per Unit	Total Army Aggregate System Support (Other Units)	Total Army
OFF				
WO				
ENL				

Total Army personnel resource requirements are:

Active _____; savings/increase of _____.
USAR _______; savings/increase of _____.
NG _______; savings/increase of _____."

<u>Example of MANPRINT manpower and personnel assessments to be included in the ROC, para 8b:</u>

"b. Personnel Assessment.

(1) Crew level cannot exceed three soldiers. No maintenance task will require the use of more than one soldier. Maintenance tasks, when compared to the predecessor system, will be decreased by 20% at the unit level.

(2) The target audience description lists the expected aptitude levels (ASVAB scores) of the soldiers who have tentatively been identified as the operators and maintainers of the XM99.

2.4 Users

2.4.1 Overview of Users and Their Functions

Primary Users. Primary MDA users will be the Directorate of Combat Development (DCD) organization within the TRADOC proponent schools responsible for developing the BOIP and QQPRI. Usually, this organization will be the Materiel and Logistic System Division. But since each DCD is structured somewhat differently, the responsible organization may vary.

As we develop detailed MDA specifications, we will identify the DCD organizations within each major TRADOC proponent by examining the AR 10 Series for each school. This series lists the organization responsible for producing requirements documents such as the SSS (System/Segment Specification).

Secondary Users. Another major MDA user will be the program manager's staff within the AMC subordinate command that provides input to the BOIP and QQPRI development process. Usually this staff is the Logistics Division or Group.

As we did for primary users we will use the AR 10-series to develop a list of the secondary user organizations. We will incorporate this list into the detailed design specifications.

Other Users. Other potential users are the BOIP and QQPRI reviewers such as HQ TRADOC (DCSOPS); the Organizational Integrator, or Force Integration Staff Officer (FISO); and the Soldier Support Center-National Capitol Region (SSC-NCR). Other reviewers include HQ AMC (AMCDRE), the MANPRINT Policy Office within ODCSPER (DAPE-ZAM), and the MANPRINT points-of-contact within the TRADOC proponent schools and AMC subordinate command. The ARI field office representatives who may provide MANPRINT support to TRADOC schools or AMC subordinate commands are also potential users.

2.4.2 Job Type

The MDA will be developed specifically for the primary users listed in the section above. These primary users are the combat developers within the TRADOC proponent school who produce the BOIP and QQPRI. The individuals who actually perform these functions within the assigned DCD division are typically Army majors or captains. We will develop a more definitive list of the job types during the development of detailed design specifications for the MDA. In order to do this, we will contact the appropriate division for DCDs for the major TRADOC proponent schools. A sample of these organizations will be contacted in the next three months so that we can present preliminary results in our final concept paper.

2.4.3 Additional Information on Users

During the development of the detailed design specifications, we will gather additional information on 1) user training background and 2) current and projected hardware and software available to users. We will develop this information by contacting the appropriate division for DCDs for the major TRADOC proponent schools.

2.5 Assumptions

The following assumptions underly development of the MDA:

Major System Focus. The MDA will describe manpower requirements for major weapon systems. Although the general logic of the MDA applies to other types of systems, we will develop the MDA's automated tools only for major systems.

Availability of HOS Subroutines. The approach we are proposing for the MDA includes embedded access to Human Operator Simulation (HOS) modeling. The current ARI supported effort towards the modification of HOS will result in subroutines that are coded in the C programming language.

Difference Between Force Structure Analysis and Manpower Determination. The MDA is an aid for determining manpower. It is not a force structure analysis tool. A manpower determination analysis determines the number of operators and maintainers needed to support a particular weapon system. A force structure analysis determines the size and composition of Army units. Force structure analysis considers tasks beyond those associated with individual weapon systems. It also assesses the impact of personnel and equipment attrition during wartime.

Attrition is beyond the scope of manpower determination as described in Army acquisition documents. As a result, tools such as AMORE that deal with attrition cannot provide a basis for manpower determination.

Operator and Maintainer Differences in Manpower Determination. The basic logic underlying determination of maintenance and operator manpower requirements is the same. It involves dividing workload demand by capacity. However, the specific elements used to calculate them in our concept are quite different. Maintenance workload is determined by computing total maintenance manhours for a given period (usually a fairly long period such as a year) and then dividing the results by a measure of capacity such as annual available maintenance manhours. Operator workload is determined by examining cognitive and perceptual and physical workload at particular points in time and then comparing this workload with the human capabilities for dealing with it. Our approach for determining manpower requirements reflects these differences. We will develop network models to represent both operator and maintainer tasks.

We will evaluate operator manning based on an operator workload model that McCracken and Aldrich developed (1984). Although we could use the same approach for maintainers, we have chosen to represent maintainer tasks use Micro SAINT networks. The networks resemble the ones that have been used to describe maintenance performance in a wide range of studies. Such studies include the Coordinated Human Resource Technology (Askren and Goclowski, 1978) and the Air Force Logistic Composite Model that the Air Force used to determine maintenance manpower requirements.

Contractor Inputs to MDA. We assume that the prime contractor will provide information on the human interface design. This information includes a description of the operation and maintenance of all major system components, including support equipment (with particular emphasis on controls and displays). Basically, the contractor will provide the level of information required by the Type B1 specification of Prime Item Development Specification (see MIL-STD-490).

The MDA will not require information on system tasks, task performance times, or accuracies from the contractor. The MDA itself will provide procedures for generating these information elements.

Use of Army Manpower Algorithms and Allowances. The MDA will use, without modification, the basic manpower determination algorithm for variable positions in AR 570-2. It will also incorporate the work capacity factors listed in AR 570-2 and the Standards of Grade Authorization found in AR 611-201.

Personnel and Training Assumptions. This concept paper focuses on the MDA's initial application. In this first application, workload estimates are based on an assumption that (1) personnel with the median level of personnel characteristics (as determined by the Personnel Requirements Estimation Aid) are performing the tasks, and (2) the type and amount of training these personnel have received is that which is most likely to be assigned (as determined by the Training Constraints Estimation Aid).

The MDA will be iterated in subsequent tradeoff analyses as part of the application of the MPT Tradeoff Analysis Aid. These tradeoffs will explore different assumptions about personnel and training.

Job Determination. The MDA will help identify jobs. The analysis will define operator jobs by assigning specific tasks to duty positions. This concept is congruent with the Army's Job Books which break out operator tasks by duty position. After the assignments have been made, the MDA's automated steps will assess how these assignments affect workload and system capability.

Maintenance jobs are defined by assigning specific tasks to MOS and skill level combinations at particular maintenance levels. The Army does not have duty positions for maintainers. The MDA will include procedures for assigning maintenance tasks to MOS and skill level combinations.

2.6 High Level Functional Requirements

2.6.1 Technical Requirements

Outputs. The MDA must output quantitative manpower requirements, by job, for a specific contractor design. These manpower requirements will include: (1) operator manpower requirements, (2) maintenance manpower requirements, and (3) Direct Productive Annual Maintenance Manhours (DPAMMH).

For maintenance the MDA will also be capable of breaking out manpower requirements by MOS, skill level, major component item (maintainers only), and maintenance level (maintainers only) and will be capable of breaking out all estimates at both the single system and aggregate level.

In addition to producing estimates of manpower requirements, the MDA will produce estimates of system availability, reliability, and operational effectiveness. These estimates will be compared with the requirements for these criteria identified by the *System Performance* Requirements Estimation Aid (SPREA) identified during the Requirements Technology and Base Activities phase of the MAP. Based on this comparison, shortfalls (discrepancies between requirements and estimates based on contractor designs) will be identified.

Role in Acquisition Process. The MDA information on manpower requirements must be designed to feed directly into the BOIP and QQPRI.

Users. The MDA must be specifically designed for use by the combat developers within the TRADOC proponent school who produce the BOIP and QQPRI.

2.6.2 Acceptability and Usability Requirements

The previous sub-section presented an overview of the technical requirements that must be met by the MDA. This section describes some of the acceptability and usability requirements which also must be met by these tools.

Produce Tailored User Outputs and Processes. Previous R&D products have not been implemented because they failed to meet the needs of individual Army decision makers. They were R&D products "in search of users". To avoid this problem in the current effort, it is critical that specific users be identified for the MDA. Furthermore, the outputs of the MDA should be

formatted so that Army users can insert them directly in MAP documents. Additionally the aids must be capable of producing results in a timely fashion and be capable of meeting the requirements of the new streamlined acquisition process. The latter requirements indicate a need for using some form of automation to support each product whenever it is cost effective to do so. Finally, to develop products that meet users needs, users must be involved in all phases of product development.

Describe "How To" Procedures. Sufficient "how to" procedures must be included in the MDA to allow Army users with minimal training to apply each product. Whenever possible, procedures should be automated to reduce user analysis requirements. However, for all automated tools, detailed procedures for obtaining input data and interpreting results should be presented. For all manual tools, detailed instructions for conducting each analytical step should be provided.

Minimize Organizational Impacts. The MDA must be designed to fit the user and not vice versa. Consequently, they must not require additional personnel to apply or cause restructuring of existing Army organizations; they must utilize computer hardware available at user locations or accessible via secure lines. Furthermore, they should use existing software whenever possible and if they require new software packages, the cost of these packages must not exceed the typical software acquisition budget for these users.

Minimize User Training. The members of the MAP community who are expected to be users of the MDA are already overburdened and understaffed. In addition, they are trying to meet increasing acquisition requirements such as MANPRINT within the context of the streamlined acquisition process. Consequently, training time for the $(MPT)^2$ products must be minimized. This requires development of user interfaces that require no prior computer experience. For example, the interface should contain built-in job aids (e.g., help commands). Finally, when formal training is required, it must be developed in accordance with Army instructional system design principles and utilize only media that are readily available or accessible to users.

Security. The MDA may be required to accept classified data and must be designed to provide acceptable levels of security.

SECTION 3 - WORKLOAD ANALYSIS AID

3.1 Overview

The purpose of this module of the MDA is to provide Army analysts with an aid for determining the manpower required to successfully perform required mission functions for a proposed system design.

The Workload Assessment Aid (WAA) will assist the analyst in determining a probable staffing plan and the feasibility of successfully performing the mission functions, given that plan, within the manpower constraints that were established as an output of Product 2. The staffing plan will be defined by the following:

- The different jobs or crew positions required.
- The tasks assigned to each job.
- The number of crew members required for each job.

The initial application of the WAA will be based on the following assumptions:

1. The operators are given an average or expected amount of training (as determined by Product 4).
2. The operators have personnel characteristic values equal to the values set by product 3, the PCEA.

The WAA will use the basic approach of hypothesis testing and operator workload analysis to identify the manpower required to successfully operate a proposed system design. In other words, with the help of the WAA, the analyst will develop a hypothetical list of jobs, tasks per job, and numbers of people per job and then test the feasibility of this configuration with respect to operator workload. By this we mean that the analyst will use the WAA to define a staffing plan and a mission scenario. The WAA will use this (and other) information to create and execute a network simulation that will determine the workload requirements of each crew member. When the simulation indicates that the proposed allocation of tasks to jobs results in excessively high workload for one or more of the operators, it means that the average operator probably can't do the job. Therefore, job and task reallocation, more operators, or a change in the system design are necessary to reduce the workload to acceptable levels.

The analyst will continue to manipulate the configuration of jobs and tasks per job until he or she finds a configuration that:

- does not produce excessively high workload for any of the crew members.
- meets the system performance requirements.
- falls within system design and manpower constraints.

When all of the above criteria have been met by a staffing plan for a given system design, the WAA will produce a set of manpower requirements reports that indicate:

- the different operations or crew jobs that were required.
- the tasks that were ultimately assigned to each job.
- the number of people required for each job.
- a summary of the workload requirements for each of the operators.
- the mission scenario parameters for which the analysis was conducted.
- a time line analysis of task performance times and accuracies.

During the tradeoff analyses conducted with Product 6, the WAA can be iterated with alternative assumptions about the personnel characteristics and amount of training received.

We should note that the purpose of this aid is <u>not</u> to predict crew performance under conditions of operator overload. To do this would add greatly to the complexity of this tool as well as to create a need for empirical research to benchmark the tool. Rather, the purpose of the WAA is to verify that a given system design with a given staffing plan will not result in levels of required workload which will exceed the capacity of the individuals and the crew. With this tool, the analyst will be able to determine points of operator overload which can lead to recommendations for system design changes and staffing changes. By avoiding the need for quantitative estimates of levels of performance degradation under overload, we have reduced the complexity of the aid and maintained the proper focus of the aid -- for the determination of manpower requirements.

The WAA will take as input the system design, a task analysis, and the operator staffing plan. The WAA will also assist the analyst in adding information to this including 1) task performance times, 2) task workload values, and 3) information about specific mission scenarios. Then, using operator workload assessment techniques which were developed and tested in other applications (e.g., Laughery, Drews, Archer, and Kramme, 1986), the WAA will compute points at which operator workload requirements exceed operator workload capacity (as defined by the analyst).

These points of excessive workload indicate deficiencies in the staffing plan and the system design. The analyst will use the WAA to address these deficiencies through a new definition of jobs, a re-allocation of tasks for each of the defined jobs, or increasing the number of operators that are used to perform each job.

Let us explain the theory and application of this workload analysis methodology to provide a clearer context for the approach.

3.1.1 The Theory Behind the WAA

Most conventional techniques (e.g., SWAT) for assessing operator workload focus on subjective examinations of workload by experts. Additionally, they tend not to define specific segments of the mission where workload is excessive.

Micro Analysis and Design has used computer modeling and simulation of the operators activities for the purpose of evaluating points of high operator workload in Army helicopters. The approach is applicable for quantitatively predicting operator workload in the earliest stages of design. The technology behind the technique, task network modeling, involves a computer simulation of human operator performance within the context of the system (hardware and software) and environment.

The fundamental approach to evaluating operator workload is to develop a computer simulation of the operator performing his activities within the context of the system he is operating and the mission he is performing. We will discuss the approach for developing operator computer models in some detail. However, to set the stage, first let us discuss the general modeling approach used, task network modeling, and the specific modeling system, Micro SAINT.

The Tools: Task Network Modeling and Micro SAINT

In previous workload analyses in which Micro Analysis and Design has been involved, models were developed by creating task networks. Task network modeling involves the decomposition of system performance into a series of subactivities or tasks (e.g., a task analysis for a human operator, a functional analysis for a helicopter). Then, the sequencing of tasks is defined by constructing a task network. A task network may also include several relatively autonomous subnetworks which, while interrelated, are also very distinctly separate such as relatively autonomous networks for the operator, hardware and software, and threats.

Additional information which is required to make a model "run" include the following for each task:

1. The mean time required to perform a task and associated distribution parameters

2. The state of the system before a task could commence (e.g., equipment availability, the aircraft being at a specific location)

3. The task or tasks which will follow when the current task is completed

4. For tasks which may be followed by several tasks, the logic associated with selection of the task or tasks which will commence after this one is completed

Micro SAINT is a product that was developed for the Army specifically to simplify and accelerate the development and use of task network models. Micro SAINT permits the modeler to construct and run all segments of a task network model by using menus rather than writing computer code. Micro SAINT will not be the only tool for the WAA, but it will serve as the building block from which our software will be constructed for the simulation portion of the WAA.

Let us now discuss task network modeling as applied to workload assessment. A sample task network model for an operator of an attack helicopter is presented in Figure 2. Note that this is a high level diagram and that each node in this network can be represented by one or more detailed sub-networks such as the one presented in Figure 3 for communications. It is conceivable that workload analysis could be conducted at either level, depending upon the availability of data.

APACHE

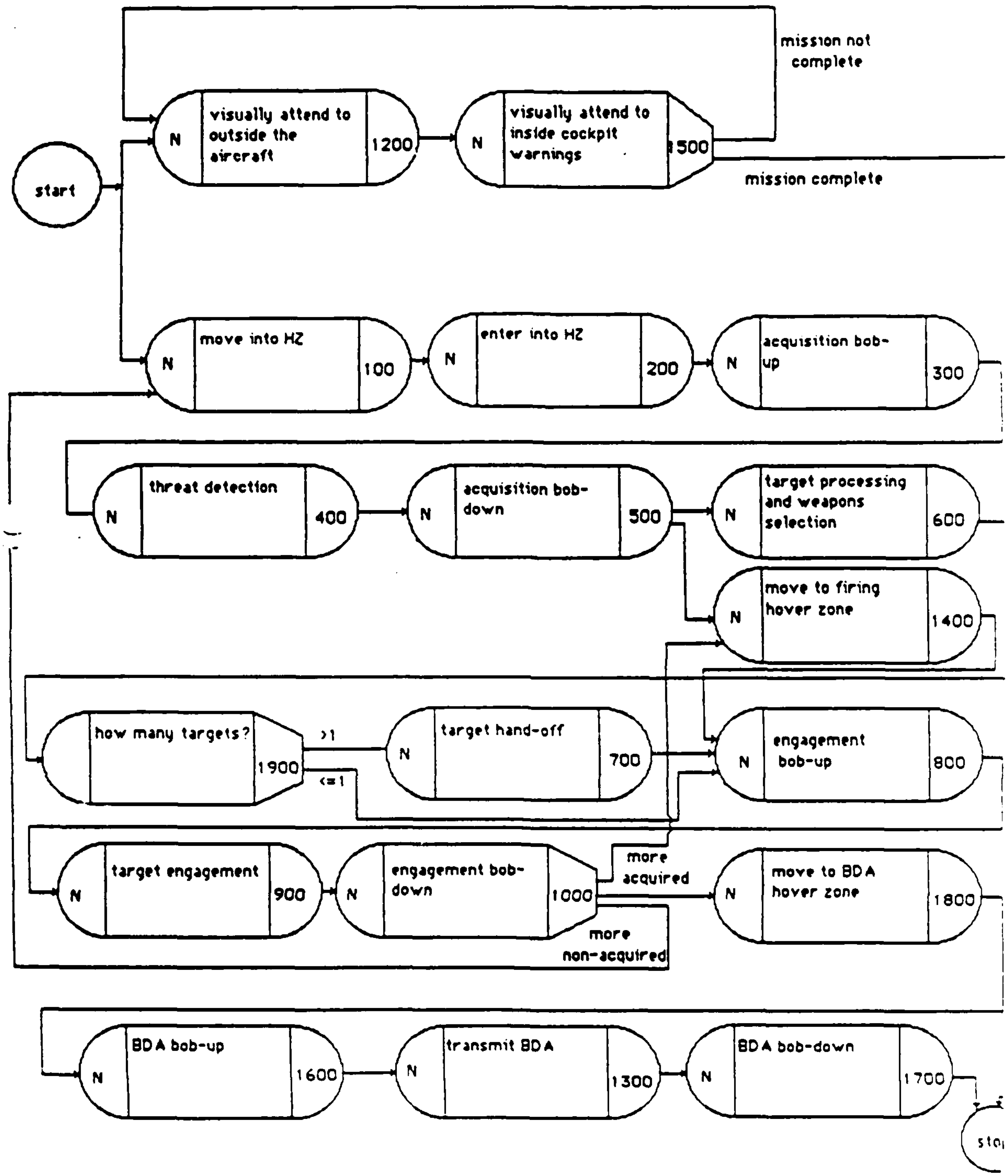

Figure 2. Sample Operator Task Network for a Helicopter Pilot.

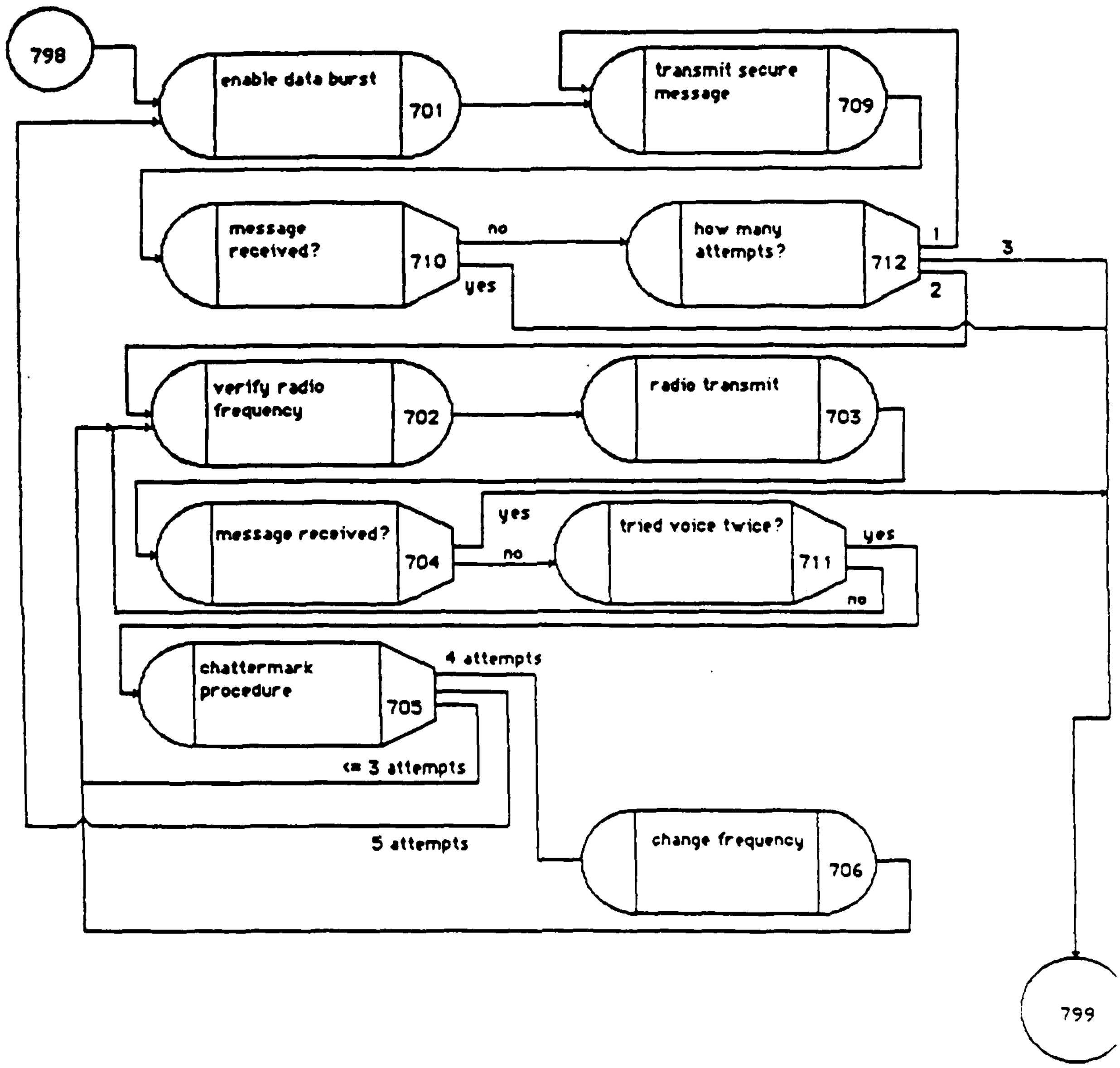

Figure 3. Sample of a Detailed Operator Task Network.

How Workload is Evaluated Using Task Network Models

To evaluate points of excessive operator workload, we propose a variation on a technique which has been used by McCracken and Aldrich (1984). Using this technique, each operator activity is characterized by the workload demand required in each of four channels, the auditory channel, the visual channel, the cognitive processing channel, and the psychomotor output channel. McCracken and Aldrich present benchmark scales for determining demand for each channel. As an example, the scale for visual attentional demands is presented below:

Value:	Activity:
1	Monitor, scan, survey
2	Detect movement, change in size, brightness
3	Trace, follow, track
4	Align, aim, orient
5	Discriminate symbols, numbers, words
6	Discriminate based on multiple aspects
7	Read, decipher text, decode

Using this approach, each operator task can be characterized as requiring some amount of each of the four kinds of attentional demand. All tasks in the operator models are analyzed with respect to these demands and values are assigned accordingly.

However, an operator is frequently not performing simply one task at a time. For example, he may be required to monitor his hover position while he receives a communication. Given this, the workload literature indicates that the operator may either accept the increased workload or begin dumping tasks he perceives as less important[1].

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[1]We are fully cognizant of the "serial" vs. "parallel" processing theories as well as other multitask human information processing theories that are currently being debated. We do not wish to minimize the impact of these theories on our approach. We recognize that they are substantial. However, if we maintain the focus that the WAA is to identify points of high workload, not hypothesizing how humans will process information during these periods, then we believe that it is reasonable to treat these tasks which the human must perform within the same time frame as being performed, essentially, simultaneously.

To factor these two issues into the computer simulations, two approaches can be incorporated: 1) evaluate combined operator workload demands for tasks which are being performed concurrently or 2) determine when the operator would begin dumping tasks due to overload. Our method focuses on the first approach.

Since the operator would frequently need to perform several tasks simultaneously and each task would have attentional demands according to the McCracken and Aldrich scale, we are able to evaluate total attentional demands for each of the four channels (visual, auditory, psychomotor, and cognitive) during a simulation by simply summing the attentional demands across all tasks which are being performed simultaneously. For example, let us assume that at some point in the mission, the operator is simultaneously reading the altimeter to compare his current altitude while he is looking at the multifunction display to evaluate his weapons status. Let us assume that the attentional demands of these tasks are as follows:

Channel	Check Altitude	Evaluate Weapons	Combined Tasks
Visual	3	2	5
Auditory	1	0	1
Cognitive	2	5	7
Psychomotor	0	0	0

The last column above indicates what his combined attentional demands for each of the four channels are. We are aware that simple summation of attentional demands into a combined score may not be fully indicative of combined attentional demands. However, there are some levels of attentional demands across tasks for which we can reasonably expect operator difficulties. In the WAA, we will provide the analyst with the opportunity to define operator "overload" at whatever magnitude he chooses with some guidance provided as to appropriate values.

In the computer simulations, we are able to assign values for the attention required in each of the four channels for each task. Then using Micro SAINT, we can obtain an estimate at any point in the simulation of the total attentional demands across all tasks. By collecting data during a simulation run, we are able to characterize the operator's attentional requirements graphically. Figure 4 shows an example of a graph for visual attention in an experiment conducted by Micro Analysis and Design for a helicopter operator workload analysis. By examining the points in the mission at which these attentional demands are high, we can assess mission segments for which operator workload will be excessive and, therefore, we can either expect degraded performance, change task allocation across operators, or define a need for more operators.

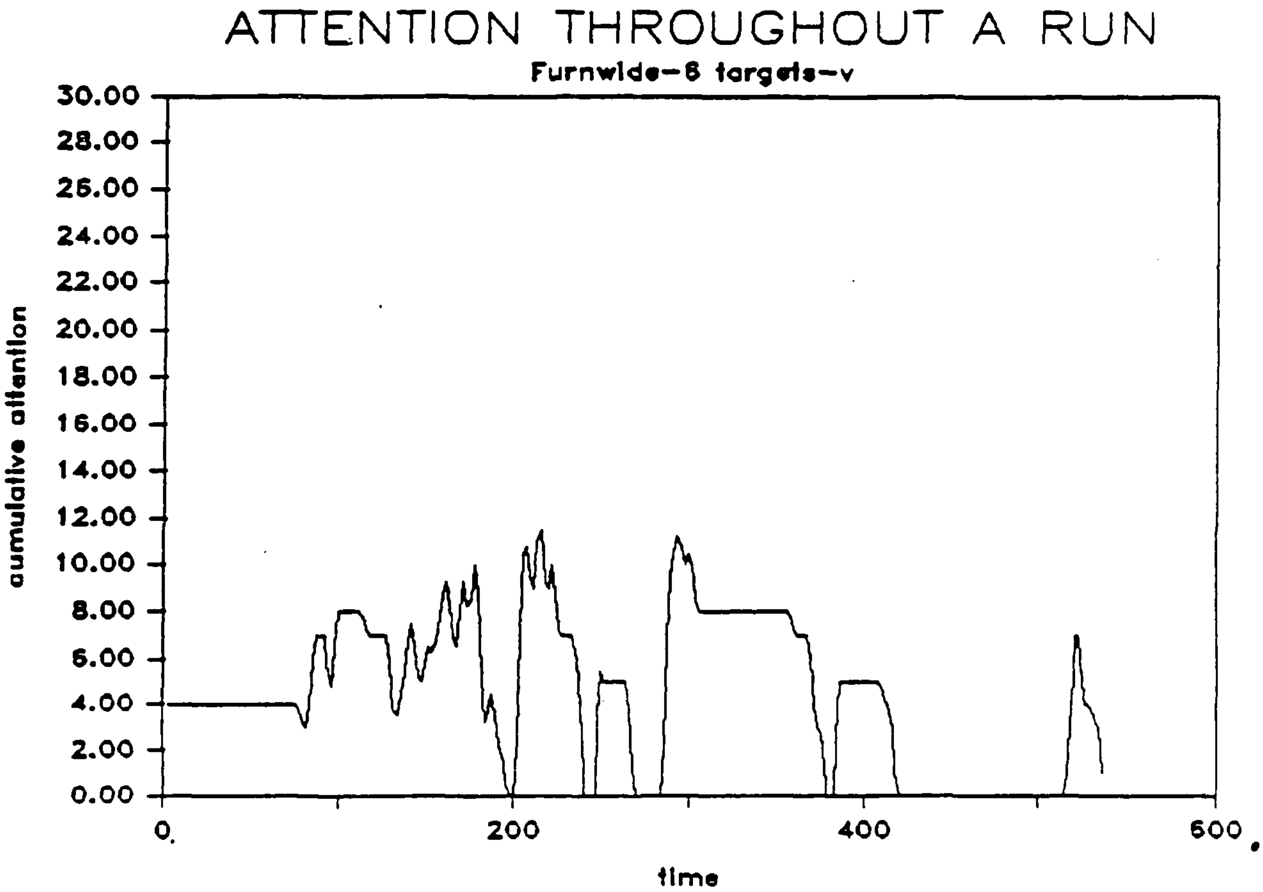

Figure 4. Sample of Visual Attentional Demands Throughout a Helicopter Mission

Additionally, we can look at aggregate attention demands by examining histograms such as the one presented in Figure 5.

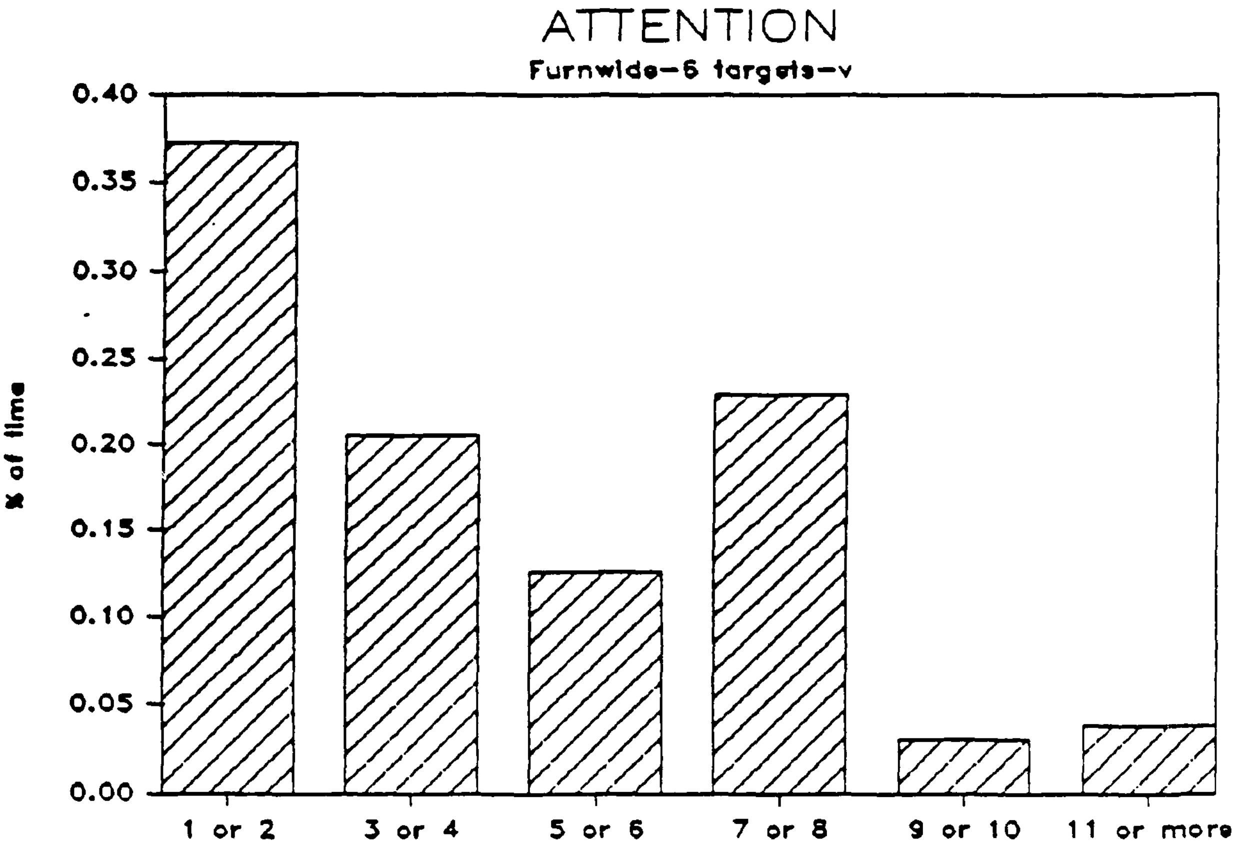

Figure 5. Sample of Histogram Presenting Visual Attentional Demands Throughout a Helicopter Mission.

While the above analysis may seem unwieldy to someone with simulation experience, modern software tools make this analysis very straightforward. As an example, Table 2 presents some labor statistics for an analysis of helicopter crew performance.

Table 2

LABOR STATISTICS ASSOCIATED WITH THE HELICOPTER WORKLOAD MODELING EFFORT

1.	Professional effort required to develop Crew Task analysis of four cockpits	30 man-days
2.	Professional effort required to develop paper model of the helicopter	3 man-days
3.	Professional effort required to develop paper model of threats	2 man-days
4.	Time to develop computer simulation from paper models and task analysis	40 man-days
5.	Time to execute one run	45 minutes
6.	Time to conduct data analyses (including generation of graphics)	4 man-days
	Total elapsed time from beginning of effort to submission of draft report	10 weeks

In constructing the WAA, we will develop a set of user interface templates and custom software to create Micro SAINT simulation models as described above. Because these portions of the WAA will be aimed directly at operator workload analysis, the user of these tools will be able to conduct the above type of analysis without having any knowledge of computer simulation, only of the operator tasks and missions.

3.1.2 Overview of the WAA Approach

The basic approach that the analyst will use to determine the manpower requirements for operators of a new or modified system design, will be hypothesis testing. The analyst will develop a hypothesis that consists of a description of the jobs or crew positions that will be required by the system design, the tasks that will be assigned to each of the jobs, and the number of crew members that will be needed to fill each job. This set of jobs, tasks per job, and number of operators per job is defined as the staffing plan.

The WAA will assist the analyst in developing a staffing plan by providing access to operator staffing information for comparable fielded systems.

The analyst will test the initial staffing plan by simulating the activities of the crew members as they perform mission functions for which the system was designed. The purpose of the simulation is to measure the visual, auditory, cognitive processing, and psychomotor workload of each operator.

If the results of the simulation indicate that the workload of one or more of the crew members is excessive, it means that the average operator probably won't be able to do the job without dumping some tasks to perform others or decreasing the proficiency of performing all tasks. When this is the case, the analyst will need to modify the staffing plan to re-allocate tasks to different jobs or consider adding more operators. However, the analyst must keep in mind that the number of operators and the tasks that can be assigned to a particular operator may be constrained by the system design. For example, if the design is a cockpit that has only two seats, the design itself has constrained the number of operators. The system design can also constrain the allocation of tasks due to an operator's access to the task that needs to be performed. For example, if a proposed helicopter design has a seat for the gunner, and a seat for the pilot, and the simulation indicates that the gunner is experiencing excessive overload in a number of mission segments, it may not be possible to re-allocate some of the gunner's tasks to the pilot due to the fact that the pilot may not have access (given the design) to the gunnery controls.

After modifying the staffing plan, the analyst will re-run the simulation to test the new hypothesis. When the results of the simulation model indicate that the workload of all of the system operators is within the capacities of average operators, the analyst will compare the simulated system performance with the output of the System Performance Requirements Estimation Aid (Product 1). If the system performance is within what is required, the analyst will compare the staffing plan with the manpower constraints that were derived as an output of Product 2.

In other words, the analyst will continue to test hypothetical staffing plans in an attempt to find a configuration of jobs, tasks per job, and number of operators per job that:

- does not produce excessively high workload for any of the operators.
- meets the system performance requirements.
- falls within the system design and manpower constraints.

When a staffing plan for a system design cannot meet all of the above requirements, then the manpower requirements for that design are unclear. The reason for this is that the manpower requirements depend on which of the above constraints are violated. If the performance requirements are violated, the number of operators may be able to stay within the manpower and workload constraints. If the manpower constraints are violated, the crew may be able to operate the system within the performance requirements, etc.

To further complicate this issue, as we stated at the outset, the WAA analysis assumes an average operator with an average amount of training. The manpower requirements deficiencies discussed above could possibly be resolved by considering operators with other personnel characteristics or amounts of training. However, these kinds of trade-offs are not within the scope of the WAA or the MDA. Therefore, when a staffing plan for a system design cannot be identified that will fall within the workload, performance, and manpower constraints, a product 6 Personnel Requirements Analysis will be required.

The hypothesis testing and workload analysis approach to determining manpower requirements for system operators offers several advantages. The first is the fact that, in most cases, the analyst will not find it difficult to define jobs and to identify the tasks that will be assigned to each job. However, when it is not clear which tasks should be assigned to which jobs or how many operators it will take, the workload modeling will tell the analyst who is busy and who isn't. Another advantage is that, no matter how jobs and tasks per job are defined, the analyst needs to know whether the operators can actually do the tasks that have been assigned to them. From a Product 5 point of view, an operator's ability to perform the tasks that constitute a job is controlled by:

- The <u>sequence</u> of tasks that must be performed. When a number of tasks need to be performed in parallel, it may not be feasible to assign those tasks to a single job, no matter how similar they are. The workload analysis performed by the WAA identifies parallel tasks that result in excessive workload for one operator.

- The <u>supportability</u> of the system design. Regardless of how jobs are defined, the system design must be able to support those jobs. For example, if a workload analysis indicates that a design for a single seat cockpit results in excessive workload for the operator, it is useless to suggest that more than one operator is needed unless the system is re-designed to support two operators.

- The <u>accessibility</u> of the operators to the controls and displays associated with tasks they must perform. Crew members can't be assigned tasks to operate equipment that they don't have access to. A simple example of this is that an operator who is assigned to a workstation must be able to reach equipment he is expected to operate. In other words, a tank driver probably can't be expected to load the main gun if he is expected to stay in the driver's seat even if he had the time.

Let us now go into some detail about the steps the analyst using the WAA will need to follow, the outputs produced by the WAA, the software elements that will be developed in creating the WAA, and the steps involved in developing these software elements.

<u>3.1.3 Steps the Analyst Will Follow in Using the WAA</u>

The steps that the analyst will follow in using the WAA to estimate the manpower requirements of a system design depend on the amount of information that is provided by the contractor. If the contractor's design documentation includes a task analysis of the operator activities and a staffing plan that defines jobs and assigns tasks to those jobs, the steps involved in evaluating that staffing plan are relatively straightforward. However, it is very likely that the contractor won't supply all of this information. When this is the case, the analyst will have to generate the missing information from other sources. In general, the less information supplied by the contractor, the more work the analyst will have to do.

In applying the WAA, the analyst will perform eleven basic steps. Section 3.2 contains a detailed discussion of each step and the sub-steps that are included within each step.

Following is a brief description of the steps (page number references for the detailed discussion in Section 3.2 are included):

1. Develop a list of the tasks in the system design that will be assigned to operators. (see page E1-59)

2. Define all crew positions (jobs). (see page E1-63)

3. Initially assign tasks to jobs. (see page E1-68)

4. For each mission to be analyzed, develop sequential relationships between operator tasks (if they are not included specifically in the task analysis). (see page E1-70)

5. Based on comparability analysis, motion-time estimation techniques, subject-matter expert estimates, or HOS modeling, develop performance times and accuracies for each operator task. (see page E1-82)

6. Assign workload values to each operator task (one value for each workload channel [i.e., visual, auditory, cognitive, and psychomotor workload]). (see page E1-89)

7. For each scenario to be studied within each mission, develop descriptions of any additional environmental, tactical, or other system conditions which are to be included in the analysis. (see page E1-90)

8. Exercise the computer simulation (which will be created directly from files generated during the above seven steps). This simulation will be exercised for each mission type and each scenario within a mission type. (see page E1-93)

9. Review the output of the computer simulation(s). (see page E1-95)

10. Determine acceptability of operator staffing plan and, if discrepancies exist between required operators and available operators, define the points at which solutions to operator overload must be found. (see page E1-111)

11. Reallocate tasks to jobs or add operators in a way that would result in successful system operation and acceptable operator workload. (see page E1-112)

The sequencing of these steps is presented in Figure 6.

3.1.4 Outputs of the WAA

All outputs of the WAA will be presented for a given mission type and a given mission scenario (including environmental and tactical conditions). For each mission scenario, the WAA will produce a variety of different analyses for the analyst to use in evaluating overall workload across a mission. Also, the WAA will provide the analyst with an indication of specific mission segments producing high workload which we will refer to as operator overload.

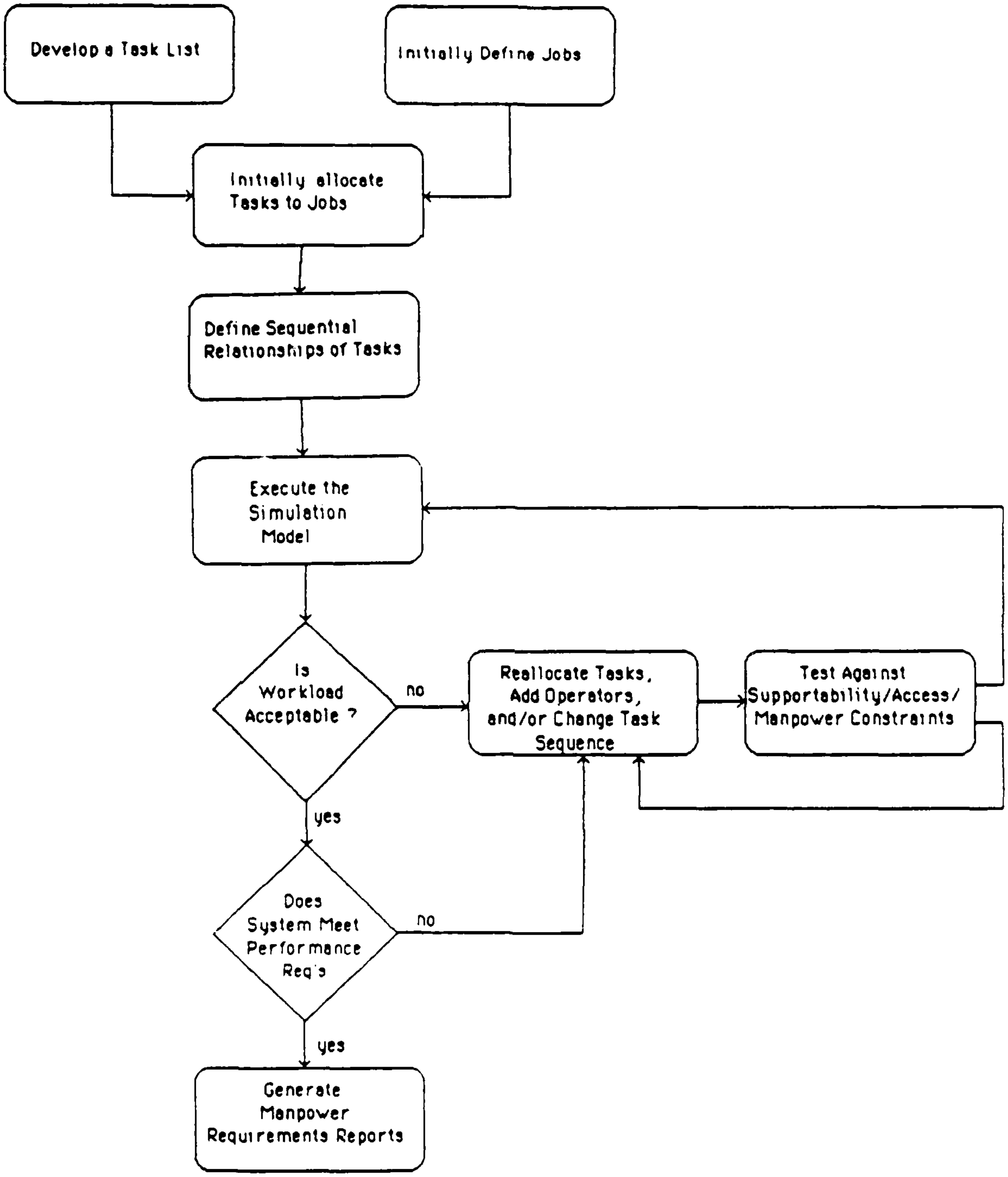

Figure 6. Steps the Analyst will follow in using the WAA

To evaluate overall workload, summary descriptive statistics will be presented for overall mission scenario workload including percentage of time spent at different workload levels and percentage of time above "critical" workload levels (with critical values either being defined by the analyst or by default values). Analysts will also be given the opportunity to define workload time "windows" representing the ability of the operator to spread out the performance of tasks during high workload situations.

To evaluate specific mission segments producing high workload, the data will be presented in several ways. First, a time line analysis will be developed of operator workload throughout each mission and scenario studied on the following four different workload channels:

1. visual
2. auditory
3. cognitive
4. psychomotor

Separate analyses will be produced for each operator. An example of one of these analyses is presented in Figure 4. Graphic overlays will be prepared by the aid so that the analyst can determine points in the scenario at which workload is high.

Second, the analyst will be given the opportunity to define "excessive" workload conditions in the context of the above four types of workload (we will define these workload scales in Section 3.2 of this paper). The analyst will be able to specify critical values for each of the four workload categories (visual, auditory, cognitive, and psychomotor), decision logic, and workload window sizes. For example, the analyst could ask for all points at which "the average visual workload over a three second period exceeded a value of seven <u>and</u> the cognitive workload exceeds a value of four). Then, the WAA would present the analyst with a series of points in the mission at which this workload threshold is exceeded. These points would be defined by mission time and all operator activities at that point in the missions.

The examination of these outputs will be facilitated by a set of guidelines that the analyst should consider in determining when workload is excessive. These guidelines or heuristics will permit the analyst to determine whether or not workload throughout the mission within the scenario being studied is likely to exceed operator capacity. Additionally, the analyst will be able to determine the points at which this overload is expected to occur. By identifying these points of expected overload, the system designers will be able to either 1) redesign the system to reduce workload at these points, 2) reallocate tasks across individuals in the operating crew, 3) propose the

addition of more crew members, or 4) define research to be conducted with actual human operators to prove that the system design does not exceed operator workload capacity.

As part of the construction of the operator simulation network, the WAA will also produce estimates of the task times and accuracies associated with a given contractor design. In addition, the WAA will contain a sub-module which will assist users in estimating task performance based on system design in terms of time and accuracy. The task performance requirements will be derived from the performance requirements set for higher level mission functions in Product 1. This same sub-module will also compare the required task performance to the estimated task performance and identify discrepancies.

3.1.5 Automated Components for the WAA

There are four fundamental types of software which will need to be developed to support the WAA:

1. The Templates for users to create files and analyze results of the analyses

2. The Libraries including historical information which the analyst can use to construct an analysis

3. The Files which the user creates representing the operator's performance within a mission

4. The Models to run the operator workload simulation and generate data for analysis

An Applications Manager will control all of the software elements. This will be the operating system in which the analyst works.

Below are the specific software elements associated with each of the above four general types of software:

The Templates

1. Function and Task Definition Template - This program will lead the analyst through the creation of lists of operator functions and tasks and assist the analyst in assigning tasks to specific operators for the system being studied. It will include definition of task performance parameters, workload requirements, and limitations on task performance (e.g., the availability of resources, the completion of other tasks).

2. The Task Performance Parameter Estimation Template - This program will lead the analyst through the estimation of task performance parameters via comparison with the task libraries, use of motion-time estimation techniques, use of task element estimation techniques (e.g., HOS), or subject-matter expert estimation. This software element will be embedded in the Function Task Definition Template, but it is of sufficient importance and complexity to distinguish for the purposes of discussion in this paper.

3. The Scenario Creation Template - This program will lead the analyst through the definition of scenarios under which the system will be studied. It will involve the development of sequencing relationships among operator tasks and the addition of non-operator tasks (e.g., tactical models) should these system elements need to be modeled.

4. The Workload Diagnostics Decision Aid Template - This program will assist the analyst in defining high workload for the simulation data analysis. Ultimately, it will assist the analyst in determining whether workload was excessive.

5. Task Reallocation Template - This template will lead the analyst through the process of determining task allocations to operators to assure that system performance as well as workload is satisfactory. The focus of this template will <u>not</u> be to estimate task performance for a given design (this is the job of the Task Performance Parameter Estimation Template). Rather, this template will lead the analyst through the process of finding acceptable task allocations from an operator workload perspective for the design to satisfy the performance requirements (identified in Product 1) while staying within the manpower constraints (identified in Product 2).

6. Reports Generator Template - This template will be similar to a menu, prompt, and command driven relational data base manager that is WAA specific. It will be used by the analyst to gain access to and retrieve data from the Task Data File. When the analyst has identified a staffing plan that meets system performance requirements, does not violate manpower constraints, and maintains acceptable workload levels for all of the operators, the Reports Generator will produce reports of:

    - the operator jobs that were defined for that staffing plan.

- the tasks that were assigned to each operator job.

- the number of operators needed per job.

In addition, the Reports Generator Template will let the analyst obtain hard copy reports of the performance parameters and workload values that were assigned to operator tasks for the current staffing plan.

The Libraries

1. Task Library - This file will include historical data on operator tasks sorted by mission area and function.

2. Scenario Library - This file will include historical data on mission scenarios sorted by mission area. Scenarios represent the sequences of operator tasks and conditions related to specific mission types.

The Files

1. Task Data File - This file will include all data which the analyst creates defining system operator(s) tasks within each function.

2. Scenario Data File - This file will include all data which the analyst created regarding specific scenarios under which system operation will be studied.

The Models

1. The Computer Simulation Model - This program will combine the task and scenario data files and run a computer simulation. Output of this simulation will include workload levels for each operator at predefined time intervals throughout the simulation (e.g., twice a second). These data will be used by the workload data analysis model.

2. The Workload Data Analysis Model - This program will allow the analyst to review workload data generated by the computer simulation. It will permit him to review points in the mission where workload was excessive based upon whatever definition of "excessive" he chooses to use. It will also generate all outputs defined in Section 3.1.4.

3.1.6 Overview of Approach for Product Development

Virtually all of this aid will be automated with the exception of some basic documentation to "get the analyst started." Therefore, let us discuss product development in the context of the development of the four categories of software described above.

The three sets of software which will need to be developed as part of product development are the Templates, the Libraries, and the Models. The fourth set of software, the Files, will be created by analysts as they use the WAA. Let us briefly discuss the development of the Templates, Libraries, and Models individually. More detail on each of these is presented in Section 5.

The Templates - As we stated earlier, the underlying software which will support the use of computer simulation is Micro SAINT. Micro SAINT currently provides a model development interface which, while very powerful, is also very general. To train analysts to use the current model development software for operator workload modeling would require special training which is undesirable.

We will use the power of Micro SAINT model execution and data generation but develop specific model development software aimed directly at operator workload analysis. Therefore, rather than a general model development interface as currently exists, we will have a very "WAA specific" interface. This will, necessarily, sacrifice some of the power of the general Micro SAINT tool but will result in a series of templates which are far easier for the analyst to learn and use.

In this task, we have identified preliminary user steps and user interfaces. We emphasize that the user interfaces are preliminary, intended more to illustrate ideas and clarify points than to provide specific interfaces. In Task 2 of this effort, we will develop specific user scripts which will be submitted to users for comments. Additionally, we will develop data flow diagrams linking user interfaces to the generation of the Files which will be used in the analysis.

The Libraries - The Libraries will be discussed in some detail in Section 4.1 of this paper. Specifically, we will discuss the types of data which will be required to feed the analyses which will be conducted in the operator workload simulation and analysis. In Section 5.1, we will discuss the data sources for initial construction of these libraries as well as preliminarily identifying the subset of mission areas for which we will develop libraries.

Our basic philosophy for developing these libraries will be to construct a set of entries into the library during Task 3 of this effort. This set will be selected so that it represents the mission areas which are likely to require MANPRINT analyses in the near future based on existing requirements. Additionally, we will embed mechanisms into the software for adding task and scenario files to the libraries as users conduct MANPRINT analyses on new systems. In doing this, analysts will be able to create their own files representing a new system and then, if appropriate, add that file to the library. For example, as a new helicopter is developed, the analyst using the WAA to analyze that helicopter's staffing requirements will create new task and scenario files which are unique to that system. At some point, this analyst would be given the opportunity to add these files into the library. Then, when the next generation helicopter is being considered, the analyst conducting the MDA analysis could draw from the libraries the most appropriate similar system (or pieces from several systems, for that matter).

In essence, we propose to develop enough pieces of the library to bootstrap the use of this tool. Then, as the aid is used, the libraries will grow reflecting new system designs.

This concept of a constantly evolving library is essential if the MDA and WAA are to have a lifespan of more than one generation of weapon systems. Obviously, if this is to be effective, consideration will need to be given to configuration management issues. These will also be discussed in Section 3.3 of this paper.

In Task 2 of this effort (development of detailed design specifications), we will develop data base formats (e.g., field definitions, record lengths) as well as software for the creation and management of these libraries. Additionally, we will finally define all data sources for the specific entries into the libraries to be developed in Task 3 of this effort.

Finally, in Task 3, we will develop the library management software and construct the subsets of the libraries defined in Task 2.

We should also note here that the collection of the data for these libraries will be performed in coordination with the development of libraries for Product 1. While Product 1 itself is intended to study systems without considering the allocation of tasks to components, the creation of the Product 1 libraries will necessarily require examination of performance data for specific systems and the components (including the human) within the system. Therefore, the data collection effort for Product 1 will be performed in conjunction with the data collection for Product 5. In fact, in many cases, the data will simply be stored in two places.

The Models - As was stated in the discussion of Templates, the basis for all models will be Micro SAINT. Again, however, the analyst will not "see" Micro SAINT, he will not "execute" Micro SAINT models, nor will he "analyze" Micro SAINT data in the ways that a user of Micro SAINT would. Rather, by creating task files and scenario files, the analyst will have created all of the information for the simulation. Our modeling software will create Micro SAINT models directly from these files, execute them, collect the appropriate data, and then analyze the data, all in the specific context of workload analysis. No data will be required of the analyst that is not needed by the WAA and no spurious data analyses will be presented to the analyst if they do not directly relate to operator workload analysis.

In this task, we have identified high level flow charts for the software model architecture. In Task 2 of this effort, we will develop detailed software specifications and, in fact, we expect to be able to begin some coding within the available time. Finally, in Task 3 we will complete all software development, debugging, and operational testing of the models.

3.2 Detailed Discussion of the Steps Followed By the Analyst Using the Workload Assessment Aid (WAA)

The purpose of this section is to provide a detailed description of the steps that the analyst will perform to use the WAA. These steps were outlined briefly in Section 3.1.3.

We are providing the detailed discussion of the WAA from the user's perspective before we present the discussion of the software design for several reasons. First, the utility of the product will depend largely on its usability, not on its architecture. Second, in reviewing this concept paper, it would be difficult to understand the collective purpose of the software elements by simply describing the elements. This would be analogous to describing an automobile to someone who has never used one by describing the engine and tires rather than describing how and why it is driven. By first describing the WAA from the user's perspective in this section and then from a software perspective in the next section we are, in essence, describing it functionally first and architecturally second.

Within the discussion of each of the steps outlined briefly in Section 3.1.3, we will present four pieces of information. First, we will provide the required inputs to the step. Inputs are separated into those data which are external to the WAA and those data which are internal to the WAA. Therefore, a data source such as a task analysis of the system is an external input whereas a library which is part of the WAA itself is an internal input. Steps can create outputs which are inputs to succeeding steps.

Second, we will define the processes which are inherent to the step <u>from the perspective of the analyst</u>. Some of these steps will involve data gathering (e.g., collecting the inputs) and some will involve manipulation of the data and analyses using the WAA.

Third, we will define the outputs of the step. These outputs will generally be either data which are used in ensuing steps or analyses which can be used by the analyst in evaluating manpower issues.

Finally, we will provide some examples of user interfaces for the various data entry, manipulation, and analyses associated with each step. Obviously, these are not final interface designs. Rather, they are intended to provide the reviewer with a sense of the types of interfaces that we intend to build into the system.

To the greatest extent possible, we have gone into detail about the specific actions involved in performing each step. Readers may conclude that there are better ways of performing these steps such as presenting certain information differently, other data sources, etc. We present the detail not because we believe it is the "only way to do things" but because it will provide the reader with the best sense of our approach to providing the Army analyst with a tool for operator manpower determination. We will, of course, modify the tool in later stages of design based on input from target users and ARI.

<u>Overview</u>

In testing each of the hypothetical sets of task assignments to operators, the analyst will undertake four basic activities. First, the analyst will create the Task File which will include all information associated with the operator's activities during <u>each</u> of the mission scenarios which he or she decides to analyze. This Task File will contain all of the information associated with each operator task including performance times, accuracies, and workload values. Second, the analyst will develop scenarios for study. These scenarios will include those which are projected to be high workload scenarios. The information will include operator task sequencing information as well as models of other aspects of the system that the analyst chooses to include in the analysis (e.g., the tactical environment). Third, the analyst will run the computer simulation and collect workload data. Fourth, the analyst will analyze the data from the simulation and determine points of operator overload as well as potential ways to alleviate this overload. Figure 7 is a flow chart of these basic activities for hypothesis testing.

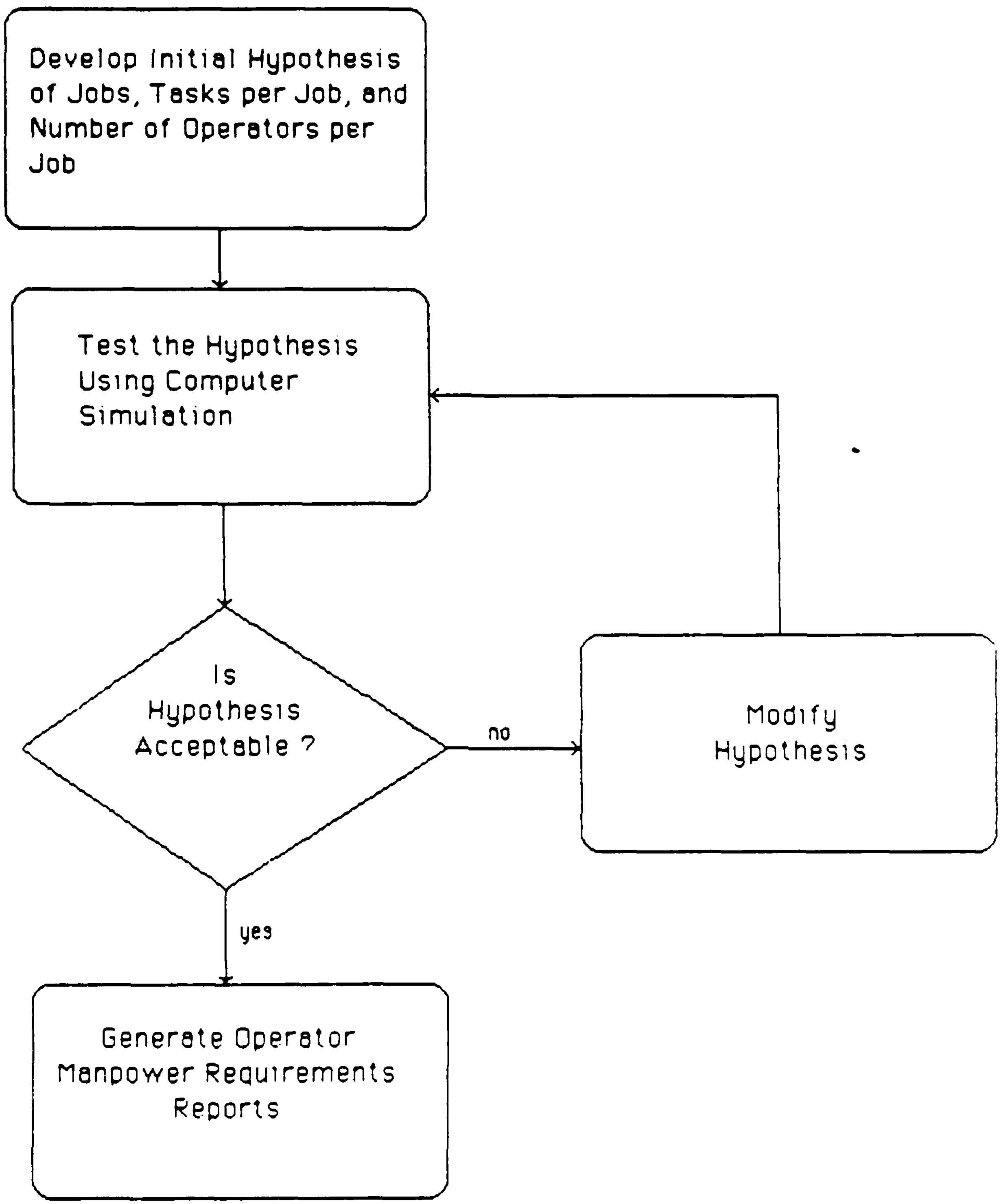

Figure 7. Top Level Flow Chart of the Hypothesis Testing Approach

In Section 3.1.3, we outlined eleven specific steps that the analyst would follow to perform the above activities. These steps are repeated below:

1. Develop a list of the tasks in the system design that will be assigned to operators.

2. Define all crew positions (jobs).

3. Initially assign tasks to jobs.

4. For each mission to be analyzed, develop sequential relationships between operator tasks (if they are not included specifically in the task analysis).

5. Based on comparability analysis, motion-time estimation techniques, subject-matter expert estimates, or HOS modeling, develop performance times and accuracies for each operator task.

6. Assign workload values to each operator task (one value for each workload channel [i.e., visual, auditory, cognitive, and psychomotor workload]).

7. For each scenario to be studied within each mission, develop descriptions of any additional environmental, tactical, or other system conditions which are to be included in the analysis.

8. Exercise the computer simulation (which will be created directly from files generated during the above seven steps). This simulation will be exercised for each mission type and each scenario within a mission type.

9. Review the output of the computer simulation(s).

10. Determine acceptability of operator staffing plan and, if discrepancies exist between required operators and available operators, define the points at which solutions to operator overload must be found.

11. Reallocate tasks to jobs or add operators in a way that would result in successful system operation and acceptable operator workload.

Figure 8 provides a flow chart of the sequencing of the above eleven steps.

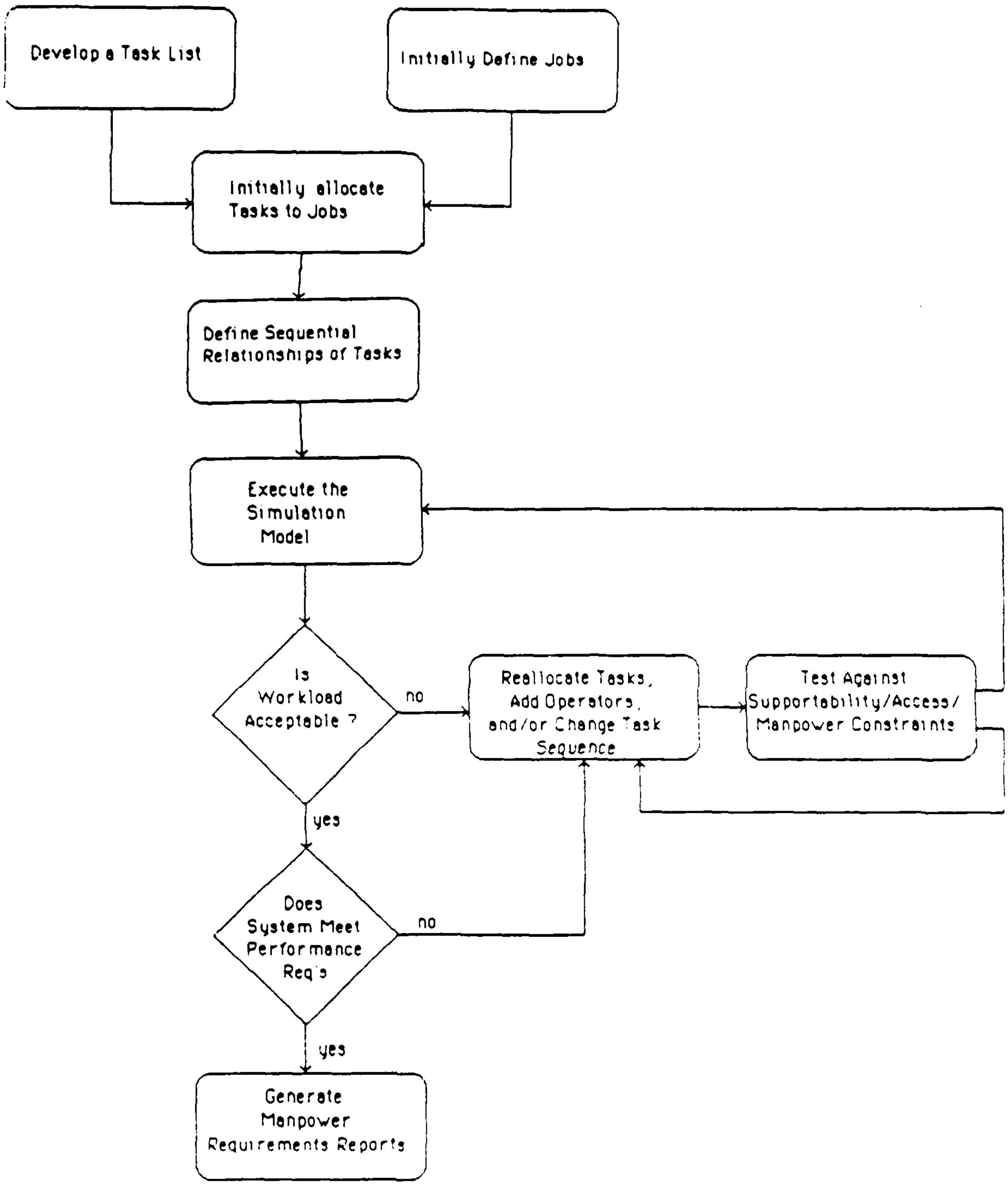

Figure 8. Steps the Analyst will Follow in Using the WAA.

The first four steps are analogous to a task analysis of operator activities. The process that the analyst will go through to obtain this information will depend largely on the availability of task analysis data supplied by the contractor who is submitting the design. It has become standard practice to include operator task analysis data requirements into Requests for Proposals for major weapon systems (e.g., LHX Draft RFP, November 1986). However, it is not yet a "sure thing" that a task analysis will be provided. If the contractor does provide task analysis data, there is no guarantee that it will be sufficient or appropriate for this analysis. If contractor task analyses are unavailable, the analyst will essentially need to conduct a task analysis from available sources of information. These first four steps represent the development of the analyst's initial hypothesis of jobs, tasks per job, and numbers of operators per job.

In Steps 5, 6, and 7, the analyst will use the WAA to enter information that will eventually be used to simulate the workload requirements and performance parameters of each operator in the hypothesized staffing plan.

Let us now go through each of the steps and discuss in some detail 1) the required input data (both internal and external including data sources), 2) the process for performing the step, 3) the output of the step, and 4) the software interfaces associated with the system software for performing that step.

3.2.1 Step 1 - Develop a list of tasks in the system design that will be assigned to operators.

Input

External input - The primary external input to this step can come from a variety of sources. The preferred input is the design documents provided to the government by the contractor designing the system. This documentation should include listings of operator tasks.

Other external input for determining an operator task list will be Subject Matter Experts, the output of the System Performance Requirements Estimation Aid (Product 1 of this effort), and task analyses associated with the predecessor or other comparable existing systems. Detailed data on the tasks for these systems are available in the Trainer's Guides, Soldier's Manuals, Job Books, How-to-Fight Manuals, or Operator's Manuals.

Internal input - When the system design documents don't identify operator tasks, the analyst may be able to identify tasks from an analogous system in the Task Library. These tasks can be used as a starting point for developing a task list for the system being evaluated.

The Process

The process the analyst will go through to develop a list of operator tasks depends on the availability and source of data. Figure 9 provides a flow chart of the sub-steps in this process.

When the contractor has submitted a task analysis with the design documentation, it will contain a list of tasks that have been assigned to operators of the system. When this is the case, the process of developing a task list is relatively straightforward. Other than physically collecting the documents, the analyst just needs to ensure that the listed tasks are at a level of detail that will facilitate this analysis. While the analysis can be performed at any level of task detail, the desired level of detail would be what is frequently referred to as the task level of detail. This level of detail is somewhere above the button pushing and switch flipping level and below the major function level such as "identify present location."

If the task detail is too shallow, the analyst has the option of decomposing the tasks. To do this would require a detailed task analysis (i.e., review system design, interview subject matter experts, etc.). The WAA will not provide the analyst with tools to do this. Rather, it will provide him with his alternatives and the implications of each which are as follows:

Refine the task analysis - This will permit a more accurate workload analysis but will require substantial work on the part of the analyst (an order of magnitude greater than that required to use the rest of the WAA).

Require the contractor submitting the design to refine the task analysis - This will permit a more accurate analysis but may delay the conduct of the analysis and pose logistical problems.

Conduct the workload analysis at the level of task definition provided - This will result in a less rigorous analysis.

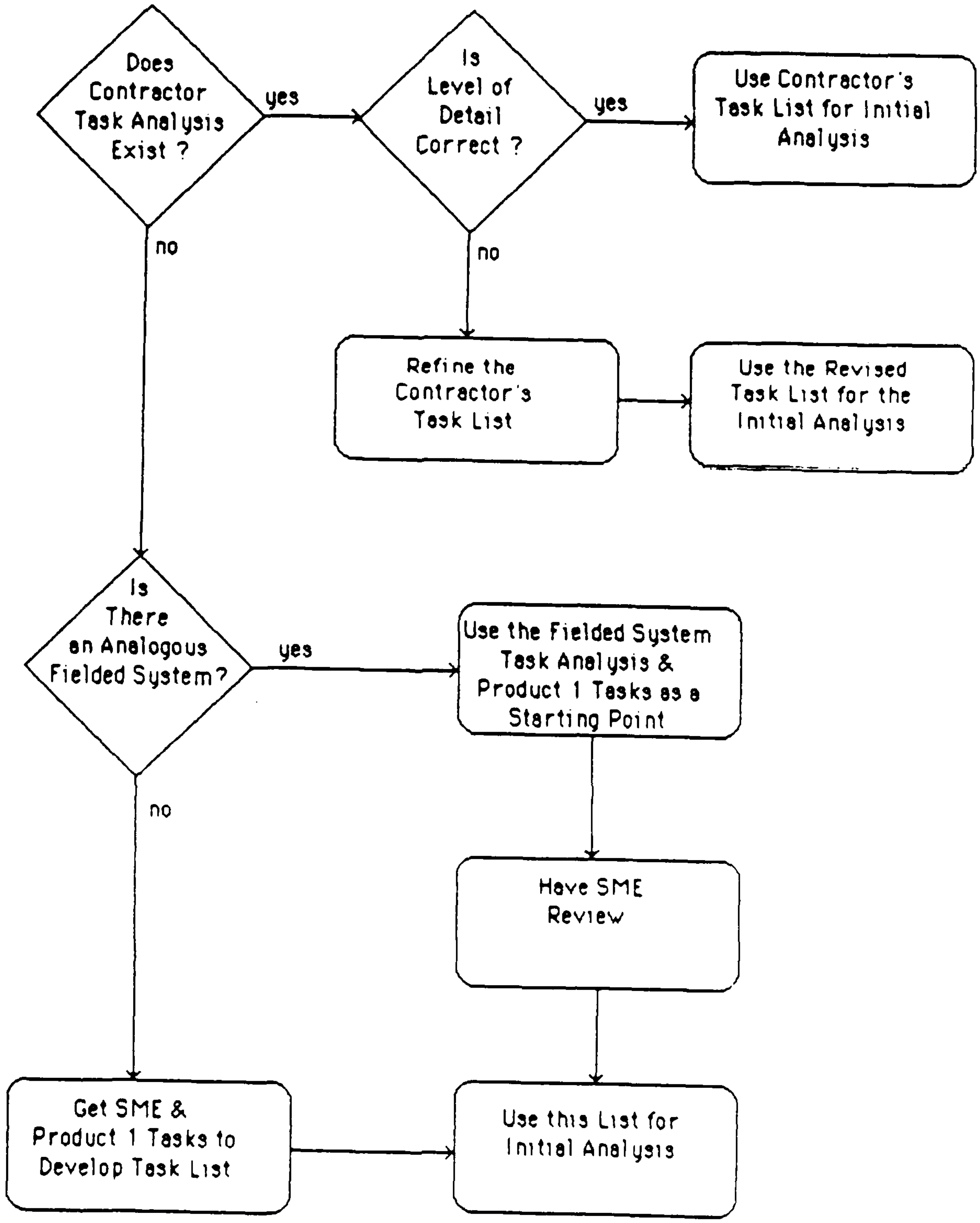

Figure 9. Develop Task List

When the contractor has not supplied an operator task list with the system design, the analyst will begin to develop a task list by first determining whether or not there is task list for a comparable system in the Task Library. If there is an adequate comparable system in the Library, the analyst will use that list and the output of system tasks from the System Performance Requirements Estimation Aid (SPREA) as a starting point for developing a task list for the new system design.

When the Task Library does not contain an adequate comparable system, the analyst will decide whether there is a comparable fielded system that is not in the Task Library. Task data for fielded systems that are not in the Task Library can be found in Trainer's Guides, Soldier's Manuals, Job Books, How-to-Fight Manuals, or Operator's Manuals.

When the analyst has obtained a task list from a comparable system, he or she will compare each operator task in the comparable system with the tasks from Product 1 and with the system design to determine if it is an operator task in the new system. When the analyst has developed a preliminary task list using this comparable system approach, it should be reviewed and verified by a subject matter expert.

When the system under evaluation is so radically different from anything currently in the field that it is not possible to find an adequate comparable system and an operator task list was not submitted with the system design, the analyst may be able to develop an operator task list solely from the output of the SPREA, the system design, and the assistance of a subject matter expert.

Output

The output of this step will be a listing of tasks which are required for operation of the system under study.

Sample User Interfaces

Because this is largely a data gathering phase, there will be little direct interaction with the system. The exception to this will be some software that will allow the analyst to search through the Task Library for operator tasks for systems that are comparable to the system under study. The tasks that are stored in the Task Library are sorted and categorized by mission area, major system type, and function. The analyst will be able to search for and select a comparable system task list by converging on that system through a series of menus. For example, when the analyst gains access to the Task Library and selects from a menu to obtain a task listing, he or she will be presented with a menu of mission areas that are included in the library. When the analyst selects a mission area, another menu will display a list

of the major systems in the library for that mission area. If this menu contains a system that is similar to the one under evaluation that the analyst wants to use for comparison with the new system, he or she can obtain a printed list of operator tasks for that system. This list of tasks will be organized according to the crew position (job) that will perform the task. This breakdown of task by job may be useful to the analyst when he or she is defining crew positions for the system under study.

In addition to the user interfaces for searching and selecting task lists from the Task Library, there will be some decision aiding software embedded within the system to aid the analyst in determining whether the contractor supplied task analysis is at the desired level of detail. These interfaces will be of a "question and answer with examples" nature such as that presented in Figure 10.

3.2.2 Step 2 - Define All Crew Positions

Input

External Input - There are potentially several sources of external input for this step. The preferred source is a document prepared by the contractor designing the system describing the crew station and all operator duty positions. Duty position assignments for predecessor or other comparable systems are available in Job Books, Operator's Manuals, How-to-Fight Manuals, and from available ARTEP data.

Internal Input - If the task listing data collected in Step 1 was obtained from the Task Library, those tasks are organized by operator job.

Process

The process that the analyst will follow to initially define operator jobs depends on the source of information available to the analyst. Figure 11 provides a flow chart of the sub-steps in this process.

If the contractor conducted a task analysis and has submitted a staffing plan with the system design, the analyst will use the contractor's definition of operator jobs for the initial analysis.

Sample User Interface to Assist the Analyst In Determining the Appropriate Level of Task Detail

Note: **Bold Entry** indicates Analyst Input

To start this analysis, you should have, in hand, the operator task analysis from which you will be working. Is this available (type yes or no)? **Yes**

This analysis will help you to determine whether the task analysis that you have to conduct the operator workload analysis is at a desired level of detail. You can begin this analysis by going through the Task analysis and selecting tasks which represent the following levels of detail:

1. The most detailed task description (i.e., the one that represents the most detailed level of operator task definition. For example, "push the button" is more detailed than "engage the target.")

2. A task that represents an "average" level of detail (take a quick look -- don't labor over the decision)

3. The least detailed task description

When you have these available, you can begin answering the following questions:

1. Is the lowest level of detail task at or below the "push button," "flip switch", or whatever would be analogous for your system level? **No**

2. Is the lowest level of task detail at least the operator function level (e.g., "engage enemy target")? **Yes**

3. ....

Figure 10. Sample User Interface to Assist the Analyst in Determining the Appropriate Level of Task Detail

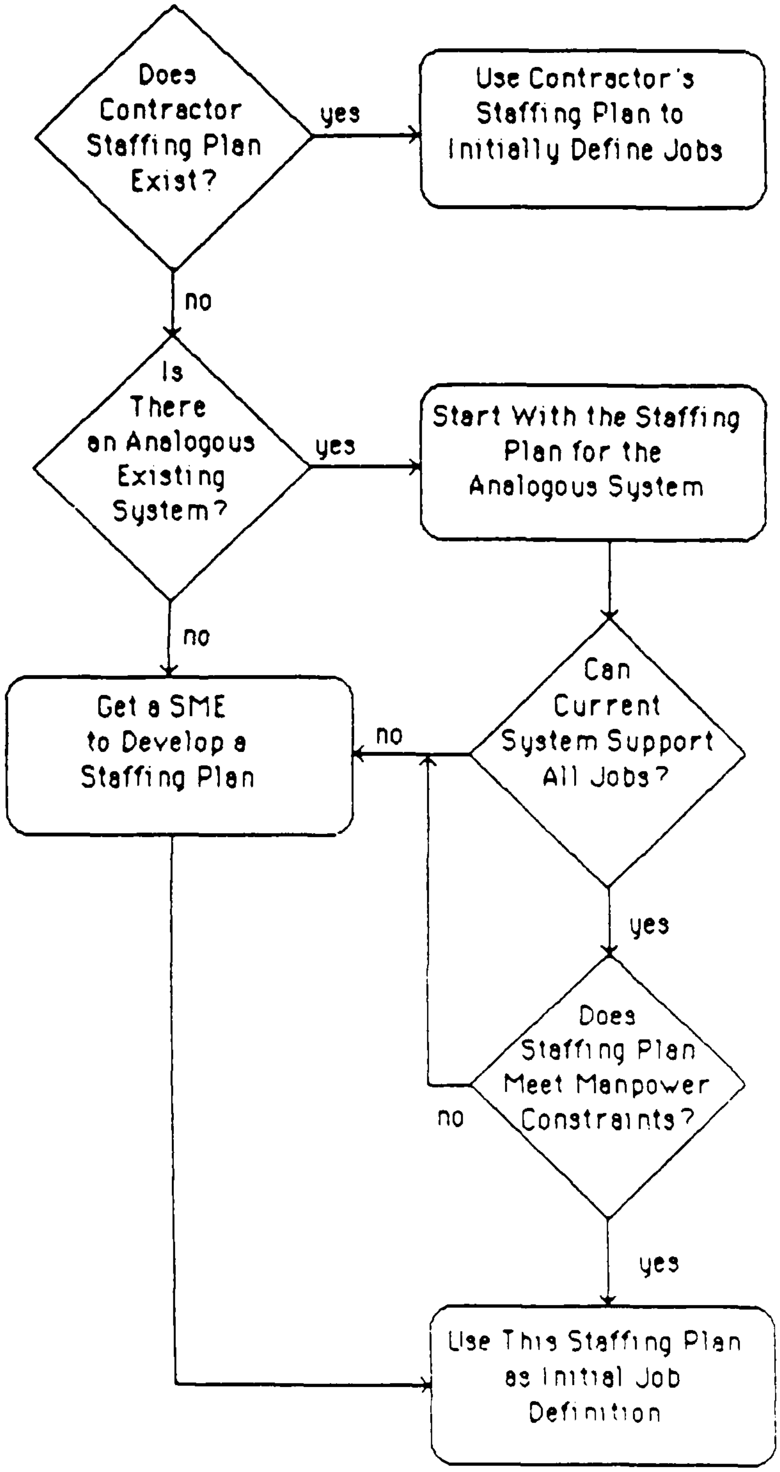

Figure 11. Define All Crew Positions.

When the contractor does not define the crew positions for the system design, the analyst will begin to develop a definition of crew positions by determining whether there is an existing system that is suitable for comparison with the system under evaluation. If the task listing that was developed in Step 1 was obtained from a system in the Task Library that was comparable to the system being evaluated, those tasks were organized by crew position. The analyst can use these definitions as a starting point for defining operator jobs for the new system.

Duty position assignments for predecessor or other comparable systems that are not in the Task Library are available in Job Books, Operator's Manuals, How-to-Fight Manuals, and from available ARTEP data.

When operator jobs have been identified for a comparable system as a starting point for defining jobs for the new system design, the analyst will need to examine the new design to determine whether it will support all of the comparable system jobs. The reason for this is that, even though the tasks that must be performed to operate the new system may be very similar to those in the comparable system, the new design could have eliminated one or more operator workstations. If the new design will not support all of the jobs that were included in the comparable system, the analyst will need to get assistance from a subject matter expert to revise the definition of crew positions. The analyst will also need to take into consideration the manpower constraints that were established as an output of Product 2 of this effort.

When the contractor does not define the operator jobs for the new system design <u>and</u> there is no existing system that is adequate for use as a comparable system, the analyst will use the new system design and the assistance of a subject matter expert to define operator jobs.

<u>Outputs</u>

The output from Step 2 will be the computerized Task Data File that, at this point, will contain only the job titles and job descriptions for each operator in the initial staffing plan.

<u>Sample User Interfaces</u>

Figure 12 illustrates a sample user interface for entering operator job titles and job descriptions into the Task Data File.

Sample User Interface to Assist the Analyst
In Describing Operator Jobs

Note: **Bold Entry** indicates Analyst Input

---

(1) Operator job title: **M60 Tank Commander**

(2) Operator job description: **The tank commander is responsible for all tank crew member activities. His primary operational responsibility is to watch for targets and alert the crew to engage them immediately.**

Type the number of the field you want to change (q when you are done)

Figure 12. Sample User Interface to Assist the Analyst in Entering Job Titles and Job Descriptions.

<u>3.2.3 Step 3 - Initially allocate tasks to jobs.</u>

<u>Inputs</u>

<u>External inputs</u> - If it is available, the preferred input for this step is a contractor developed operator staffing plan that allocates each of the operator tasks to a duty position or job.

Other external input may be obtained from subject matter experts and from Army manuals, Job Books, and task analysis data for comparable or predecessor systems.

<u>Internal inputs</u> - The task listing that was an output of Step 1 and the Task Data File that was created as an output of Step 2.

<u>Process</u>

The process that the analyst will go through to make an initial assignment of operator tasks to crew positions will depend on the source and availability of task analysis data to the analyst. Figure 13 provides a flow chart of the sub-steps involved in this process.

If the contractor has submitted a staffing plan with the system design that indicates task assignments to duty positions, the analyst will use that set of assignments as a starting point for the initial analysis.

When the analyst has used comparable system data to develop the task listing and crew position definitions, he or she will also use the assignment of tasks to jobs in those comparable systems as a starting point for assigning tasks to jobs in the new system.

When the operator task listing and the definition of crew positions was accomplished directly from the system design and subject matter expert input without the aid of a contractor developed staffing plan or comparable system data, the analyst will have to use those sources to initially assign tasks to jobs.

For each potential task assignment to a crew position, whether it be with the aid of a contractor supported staffing plan or comparable system data, the analyst will need to examine the proposed system design to ensure that it will support that task assignment in terms of giving the operator access to controls, displays, and other equipment. When the design will not allow a task to be assigned to an operator due to location of equipment or other operator interface constraints, the analyst

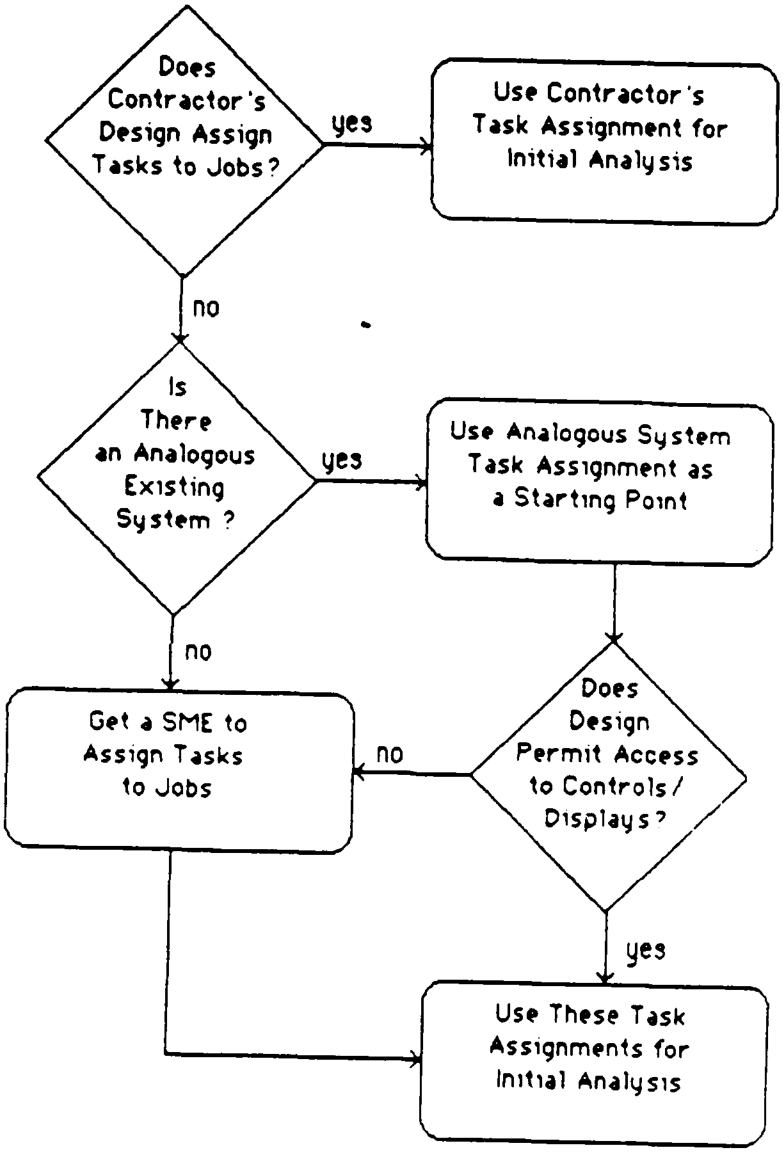

Figure 13. Initially Allocate Tasks to Jobs.

will need to reallocate that task to another operator. This reallocation may require input from a subject matter expert.

The information that will be required for each task will, at this point, simply be task titles and descriptions. Descriptions will always be optional.

Output

The output of Step 3 will be a Task Data File that includes an initial assignment of all identified operator tasks to specified crew positions or jobs. At this point in the analysis, the Task Data File will not yet contain task performance parameter estimates.

Sample User Interfaces

Figures 14 and 15 illustrate sample user interfaces that will assist the analyst in assigning tasks to operator jobs and entering task descriptions into the Task Data File.

3.2.4 Step 4 - For each mission to be analyzed, develop sequential relationships between operator tasks

Inputs

External Input - Step 4 will have as input the mission area analyses, the mission simulation models developed in Product 1, the system O&O Plan with operational mode summary, MAA and MADP results, the contractor trade studies examining operator workload (if any have been conducted), and subject matter expertise as required to supplement these analyses.

Task sequence information from the predecessor or other comparable systems may also be useful. Such information is available in Soldier's Manuals, Job Books, Operator's Manuals, and ARTEP data.

Internal Input - The Task Data File created in Step 3 and the Mission Scenario Library.

Sample User Interface to Assist the Analyst
In Assigning Tasks to Operator Jobs

Note: **Bold Entry** indicates Analyst Input

---

(1) Operator job title - **Tank Commander**
Mission Area - **Armor**
System type - **M60**

(2) List of operator tasks already assigned to this operator job:

site selection
target acquisition
lay the gun
call "gunner, ammo, target"
.
.
.
.

Type 1 to change the operator on which you are working

2 to add, modify, or delete tasks from the operator task list

3 to review more tasks from the task file

4 to review more tasks from the task library

Figure 14. Sample User Interface to Assist the Analyst In Assigning Tasks to Operator Jobs

Sample User Interface to Assist the Analyst In Entering Tasks into the Task Data File

Note: **Bold Entry** indicates Analyst Input

---

(1) Task title: **Ammo selection**

(2) Mission area: **Armor**

(3) System type: **M60 Tank**

(4) Task description: **Depending upon the target type, distance, and environmental conditions, the type of ammo to be fired at the target must be selected.**

Type 1, 2, 3, or 4 to change any of the above fields

5 to review the task performance parameters associated with task

6 to review other tasks from the task library

Figure 15. Sample User Interface to Assist the Analyst In Entering Tasks into the Task Data File.

Process

The purpose of this step is for the analyst to link the tasks which will have been identified in the previous step. To accomplish this, two major substeps must be undertaken:

1. Identify scenarios
2. Define sequential relationships among operator tasks

Let us discuss each of these substeps individually.

Identify Scenarios - At this point in the process, the analyst must become familiar with the scenarios for which he would like to study operator workload. Workload cannot be studied from a purely operator or hardware and software system perspective since one cannot look at a system design and conclude whether it will require more workload than an operator can manage. Rather, operator workload must be studied in the context of the operational environment. In a military environment, this translates to the identification of the mission scenarios.

Obviously, not all mission scenarios can be studied for a particular system. Every system can be involved in, essentially, an infinite number of scenarios. Therefore, the analyst will need to carefully select the scenarios in which operator workload is expected to be the limiting factor.

The first goal in this step, therefore, is to determine the probable high-workload missions and mission segments. There will be several sources of data to which the analyst will be led by the WAA, including the Operational Mode Summary, Mission Profile in the O&O Plan, the threat description in this and other documents, and the TRADOC standardized scenario descriptions (SCORES).

As part of the MANPRINT analysis for most future weapon systems, workload analyses will need to be performed (e.g., LHX Draft RFP, November 1986). Therefore, as part of the contractor input being evaluated with the WAA, a workload analysis may be available. In this workload analysis, high workload mission segments and scenarios will be identified. These analyses can serve as starting points.

However, consistent with the philosophy that we will be conducting an independent analysis of contractor conclusions, not simply relying on contractor data, this analysis should be reviewed by subject matter experts to verify that these are expected to be the highest workload mission segments. Additionally, the subject matter experts should then prioritize

the mission segments in the order of those with the highest expected workload, since it will not always be possible to study all high workload mission segments.

In most cases, the contractors will not have conducted workload analyses as part of the trade studies. This being the case, the subject matter expert will need to provide input as to the most likely high workload mission segments.

Finally, the analyst will need to refer to the mission area analysis to develop an understanding of the specific tactical and environmental conditions in which the system will operate. To the greatest extent possible, the following should be identified as they relate to each of the mission segments identified by the subject matter experts:

1. Threat and target types

2. Maximum threat and target density

3. Stressful environmental conditions

4. Climate, terrain, and other induced stressors

<u>Develop Sequential Relationships among Operator Tasks</u> - In this substep, the analyst must translate the scenarios developed in the previous substep into groups and sequences of tasks which the operator must perform. Three elements must be defined: 1) the set of tasks which must be performed, 2) the order in which the tasks must be performed, and 3) the conditions controlling task performance.

The primary aid presented to the analyst will be access to the Mission Scenario Library. The Mission Scenario Library (which will be discussed in greater detail in Section 3.3) will include sets of tasks from previous systems organized by mission segment within system type within mission area (e.g., armor-attack mission segment within attack helicopter system within the aviation mission area).

The analyst, at a workstation, will begin the analysis with the highest workload mission segments identified in the previous substep. He would then call up the "Review Mission Scenarios" portion of the software from the Application Manager. The analyst will then identify the mission area and the general system type from a series of menus. If the system is truly unique or the similar systems have not been included in the library, then he may have to construct the mission scenarios from scratch.

If he or she can identify an analogous system type, the analyst will be given a list of mission scenarios which currently reside in the library for that system. The list will be a set of scenario titles. As the analyst finds scenarios which he believes are analogous to those he or she wishes to study, he will be able to review detailed descriptions of the scenarios in any of the following forms:

1. One-page descriptions of the scenario

2. Drawings of the sequencing of tasks in the scenarios

3. Detailed descriptions of each of the tasks within the scenarios

An example of each of the above three types of information is presented in Figures 16, 17, and 18, respectively. These displays will be presented on-line at the analyst's workstation or in hard copy.

Based on these reviews the analyst should be able to determine which, if any, of the scenarios in the library are appropriate.

If none of the available scenarios are appropriate, then the analyst will have to construct task sequencing relationships from scratch. To facilitate this, the WAA will provide an on-line tutorial of the types of data that will need to be collected in order to construct the sequencing relationships. The primary data source will, necessarily, be subject matter experts. More detailed analysis will most likely be beyond the available time limitations on the analyst at this point and the additional information quality would probably not result in a commensurate improvement in workload prediction.

As the analyst reviews the analogous scenarios, he will begin constructing his particular scenario. Recall that the tasks in the system under study may not exactly match the tasks in the analogous scenario. Likewise, the analogous scenario itself may not exactly match. Therefore, some interpretation on the part of the analyst will be required. This interpretation will require the following decisions:

1. How do the tasks in the analogous scenario compare to those defined in the system under study? - Different levels of task decomposition and different system designs could affect both the degree of task similarity and, therefore, the appropriateness of the analogous scenario.

Sample One Page Scenario Description

---

(1) Scenario Title - Anti Armor Engagement

(2) Mission Area - Aviation

(3) System type - Apache helicopter

(4) Scenario description:

This scenario begins at the entry of the aircraft into the hover zone below tree level where threats are known to be (the actual number of threats may vary). Weather conditions are VFR. The helicopter pops up to acquire the targets and then pops down to prioritize the targets. Then, the helicopter begins a series of pop ups, engage targets, pop downs, change positions, until all targets have been engaged or all weapons are expended. At this point, the helicopter pops up for battle damage assessment and leaves the area (end of scenario)

Figure 16. Sample One Page Scenario Description.

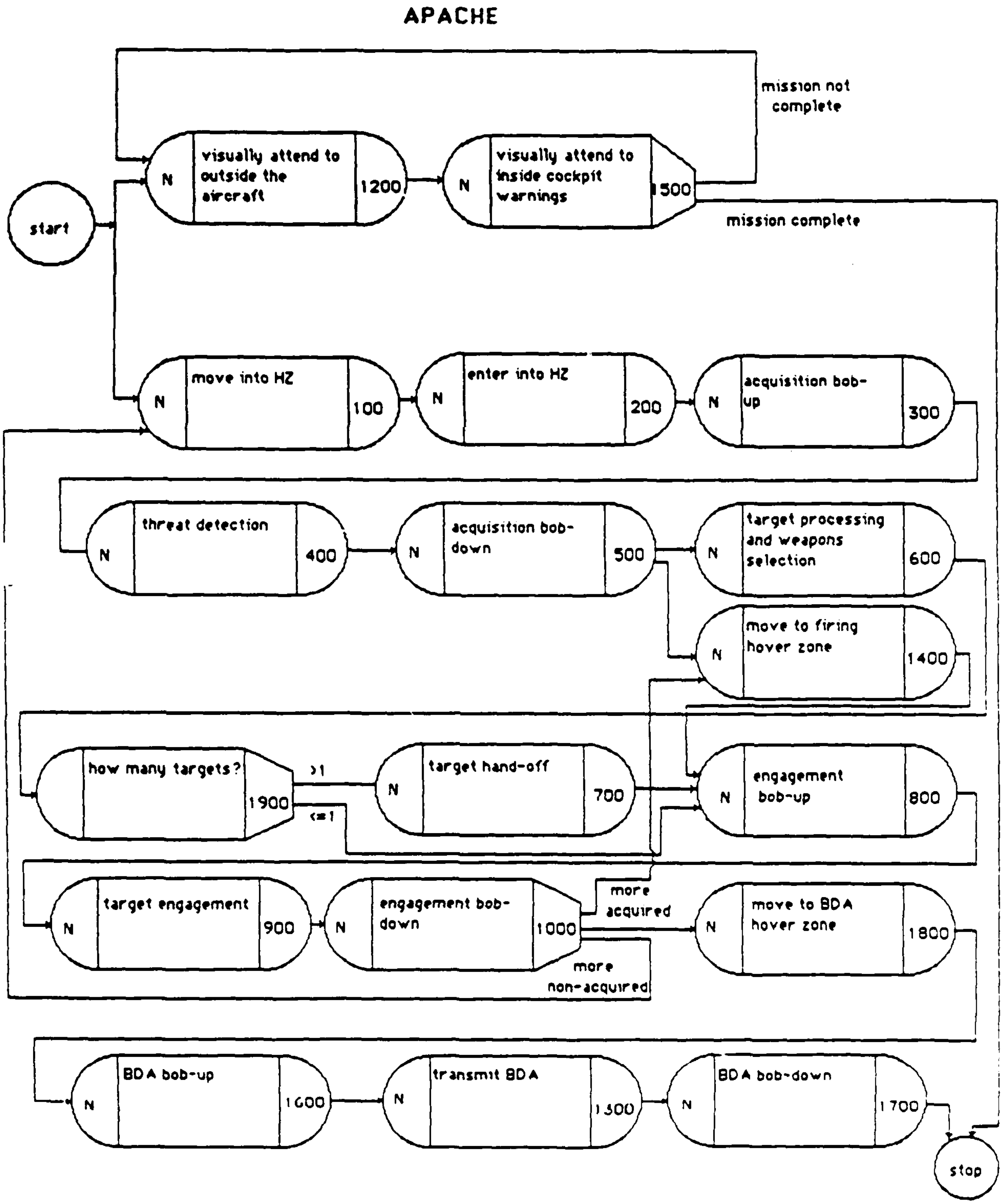

Figure 17. Scenario Diagram

Detailed Description of Tasks within Scenarios

Note: **Bold Entry** indicates Analyst Input

Scenario title - Tank one-on-one engagement

(1) Task title: **Ammo selection**

(2) Mission area: **Armor**

(3) System type: **M60 Tank**

(4) Task description: **Depending upon the target type, distance, and environmental conditions, the type of ammo to be fired at the target must be selected.**

Type 1, 2, 3, or 4 to change any of the above fields

5 to review the task performance parameters associated with this task

6 to review other tasks from the task library

Figure 18. Description of Tasks Within Scenarios.

2. Is the inherent sequencing of tasks fundamentally the same for the new system? - Inherent sequencing, defined as the sequential relationships among tasks which are independent of operating conditions, will often differ as a function of the new system design. Some tasks may not exist for the operator because they have been automated, others may be fundamentally different.

3. Is the conditional sequencing of the tasks the same for the new system? Conditional sequencing, defined as the way that task sequencing is driven by conditions of operation, may differ. We do not expect detailed dynamic models of operator task sequencing to be included in the WAA (e.g., models that consider system reaction to threat sensing if no human performance is involved). Recall that the purpose of the WAA is operator workload analysis, not system simulation. However, when closed-loop aspects of operator behavior are germane to workload, then some modeling of these aspects of the system may be included. However, operator reactions to different operating conditions may be different from system to system and these differences will need to be recognized.

The analysts will make these comparisons of the library scenario to the set of task sequences they must create by moving between or displaying simultaneously six windows (they will be able to display up to two windows simultaneously) - three windows as described above (summaries of the scenario, drawings of the task sequencing, or detailed task descriptions) defining the system they are developing and the same three windows describing the library scenario. The nature each of these windows was previously presented in Figures 16 through 18.

Outputs

Through this interactive process, sequences of tasks and the definition of how their performance is mitigated by conditions will be defined. In doing this, the analyst will have provided the data required for a computer simulation of operator behavior. The next step will be to assign performance parameters to tasks.

Sample User Interfaces

Interfaces for defining task sequencing which is unique to the system under study are presented in Figures 19 and 20 for inherent sequencing differences and conditional sequencing, respectively.

Sample User Interface for the Definition of Inherent Sequencing

Note: **Bold Entry** indicates Analyst Input

---

(0) Scenario title - Tank one-on-one engagement

(1) Task title: **Ammo selection**

(2) Mission area: **Armor**

(3) System type: **M60 Tank**

(4) Operator: **Tank commander**

(5) Possible following tasks (6) Decision type

a. **Select heat seeking missile** **Tactical**

b. **Select Machine guns** **Tactical**

c. **Cease engagement** **Probabilistic**

Enter 0 to change the scenario on which you are working

1, 2, 3, or 4 to change the task on which you are working

5 to change information on the task sequencing

Figure 19. Defining Inherent Sequencing.

Sample User Interface for the Definition of Conditional Sequencing

Note: **Bold Entry** indicates Analyst Input

---

(0) Scenario title - Tank one-on-one engagement

(1) Task title: **Ammo selection**

(2) Mission area: **Armor**

(3) System type: **M60 Tank**

(4) Operator: **Tank commander**

(5) Possible following tasks (6) Decision type (7) Decision Variable

a.	**Select heat seeking missile**	**Tactical**	**THREATYPE**
b.	**Select Machine guns**	**Tactical**	**THREATYPE**
c.	**Cease engagement**	**Probabilistic**	**.95**

Enter 0 to change the scenario on which you are working

1, 2, 3, or 4 to change the task on which you are working

5 or 6 to change the inherent task sequencing

7 to change the conditions of sequencing

? **7**

Enter the letter corresponding to the decision you want to work on
? **a**

The following expression describes when the operator will select this course of action: Select heat seeking missile
IF THREATYPE == MOBILE OR THREAT

Type in a new expression or type 'm' to change this expression

Figure 20. Defining Conditional Sequencing.

3.2.5 Step 5 - Based on comparability analysis, motion-time estimation techniques, subject-matter expert estimates, or HOS modeling, compute performance times for each operator task

Inputs

External Input - The contractor's design document, particularly the portion describing the user interface will be the primary input. Also, subject matter experts may be required.

Internal Input - The output of Step 3, the Task Data File, will be the main input (it is the Task Data File which we will be augmenting in this step). Also, the Task Library will be used.

Process

Step 5 will require the analyst to estimate parameters associated with operator task performance for each of the tasks identified in Step 1 and added to the Task Data File in Step 3. The parameters which will need to be identified will include the following:

1. Mean task performance time

2. Standard deviation of task performance time

3. Probability of making an error in the task and, therefore, forcing the task to be re-performed

All of these parameter estimates will represent expected values under the stated operating conditions for an operator with the personnel characteristics and training equal to the constraint values determined by the PCEA and TCEA, respectively.

Step 5 will, in many ways, be similar to Step 4 in that the analyst will examine the Task Library to determine whether analogous tasks can be found from earlier systems for each operator task in the Task Data File. If these analogous tasks exist, then the analyst can use their task performance parameters to set those parameters in the new system operator tasks.

If analogous tasks do not exist in the Task Library, then the analyst will be provided with some fairly powerful tools for estimating task performance time should he choose to use them. In addition to the Task Library and the obvious alternative, subject matter expert opinions, we will provide two additional tools, motion-time study methods (for motor-intensive tasks) and HOS task time estimation methods (for information processing-

intensive tasks). The software to lead the analyst through the application of these routines will be embedded within the Task Definition Template of the WAA. The details of this software will be presented in Section 3.3.

When analogous tasks exist in the Task Library - When analogous tasks exist, the analyst performing this step will follow steps virtually identical to those that were followed in the previous step. He or she will review listings from the Task Library by examining tasks from similar mission segments within system types within mission areas. Then, through the use of a windowing technique similar to that described in Step 4, the analyst will examine the analogous task from the Task Library and decide if it is sufficiently similar to the task from the system being studied. When the analyst finds one that is sufficiently similar, all task parameters will be copied from the task in the Task Library to that in the Task Data File.

When analogous tasks do not exist - In many new systems, new tasks may exist reflecting new technologies or tasks from other systems may be sufficiently different that the analogy is inappropriate. The analyst will simply have to use judgment to make this determination.

When this occurs, the analyst will be given two options for estimating performance parameters, 1) collecting subject matter expert opinions or 2) constructing estimates based on further task decomposition. The tradeoff is obvious -- time vs. accuracy of the estimate. The analyst will be provided with guidance to help make that decision[2]. The guidance will include the following considerations:

1. How much time (subject matter expert plus analyst) will be required to further decompose the task? Specific considerations will be given to complex vs. simple tasks will be included in the form of a "time required to estimate" algorithm.

2. How much more accurate is the estimate likely to be if decomposed vs. simply estimated? Specific considerations will be given to the availability of qualified subject matter experts to assist in the breakdown, the "fluidity" of the system design as it relates to the task (i.e., how much the task is likely to change during the system design process), and the predictive power of the estimation technique (HOS or motion-time analysis).

[2]Of course, the analyst will be able to avoid this analysis and say "I (don't) want to decompose the task."

The analyst will be asked a series of questions relating to the above items. At the completion of this analysis, the WAA will give him or her its recommendation as to how much time it is likely to require to obtain this estimate and whether it will result in a "much better," "slightly better," or "probably no better or worse" estimate of performance. These suggestions will be made through applying some very simple heuristics to the analyst's input.

Should the analyst choose to decompose the task and estimate performance parameters, the software will lead him or her through the process of decomposing the task into task elements. Then, it will pull the times associated with each of the task elements from the appropriate algorithm. Again, if the task is largely a motor task, the task elements will be drawn from a motion-time study data base. Motion-time study techniques have been used for decades by Industrial Engineers and are readily available and fairly accurate. If the tasks require a substantial amount of information processing, then HOS time estimation algorithms will be employed.

Output

The output of this step will be task parameter performance estimates for all of the tasks in the Task Data File. These will be included in the Task Data File.

Sample User Interfaces

Figures 21 through 24 present sample user interfaces for the following analyst activities, respectively:

- Selection of the appropriate portion of the Task Library to review
- Windows comparing task performance parameters in the Task Library to those assigned in the Task Data File for a particular task
- Decision analysis to determine whether to use subject matter experts or task decomposition
- The development of task performance parameters using motion time analysis techniques

Sample User Interface for the Selection of the Portion of the Task Library to Review

Note: **Bold Entry** indicates Analyst Input

The name of the task for which we are currently looking for a similar task in the library is described as follows:

(1) Task title: Ammo selection

(2) Mission area: Armor

(3) System type: M1 Tank

(4) Task description: Depending upon the target type, distance, and environmental conditions, the type of ammo to be fired at the target must be selected.

Do you want to restrict the search to tasks in the Mission Area ARMOR (type yes or no)? **Y**

There are 400 tasks in this Mission Area and they belong to the following types of systems:

a. M60 Tank

b. M60A Tank

Do you want to restrict search to any of the above systems? **N**

Enter any key words that must be in the task title for tasks to be displayed (or hit return to review all 400 tasks) - **AMMO AMMUNITION**

Below are all tasks from the Task Library in Mission Area ARMOR with the words AMMO or AMMUNITION in them -

a. Check AMMO
b. Load Ammunition
. .
. .
f. Select Ammunition

Enter the letter number for any task that you would like to review? **F**

Figure 21. Review Portion of Task Library.

Sample User Interface for the Comparison of
ask Library Data to the Assigned Task Performance Data

Bold Entry indicates Analyst Input

---

me of the task for which we are currently WORKING ON is
bed as follows:

'ask title: Ammo selection
Iission area: Armor
System type: M1 Tank
'ask description: Depending upon the target type, distance, and environmental conditions, the type of ammo to be fired at the target must be selected.

IED TASK PERFORMANCE PARAMETERS

Mean Performance Time - **1.5 seconds**
Standard deviation - **Default (one-third of the mean)**
Probability of making an error - unassigned

the number of the field you want to change or 'return' to
ate that you have completed work on this task - **3**

---

ame of the task FROM THE LIBRARY is as follows:

Task title: Ammunition selection
Mission area: Armor
System type: M60A Tank
Task description: Depending upon the speed of tank movement, the target type, distance, and environmental conditions, the type of ammo to be fired at the target must be selected.

RY TASK PERFORMANCE PARAMETERS

Mean Performance Time - 1.8 seconds
Standard deviation - 0.6 seconds
Probability of making an error - .02

: 22. Comparison of Task Library Data to Task Performance

Sample User Interface for Aiding the Analyst
In Deciding How to Assign Task Performance Parameters

The task that we are considering is as follows:

Task title: Ammo selection
Mission area: Armor
System type: M1 Tank
Task description: Depending upon the target type, distance, and environmental conditions, the type of ammo to be fired at the target must be selected.

Answer the following questions for this task:

(1) Are the system components associated with this task designed in detail (e.g., software elements and hardware designs have been defined)? Type yes or no - NO

(2) Do more than 25% these system components already exist (e.g., are they "off-the-shelf" items)? If you are unsure, take a guess?

(a) less than 25% off the shelf
(b) more than 25% off the shelf

type a or b - A

(3) Are the task elements that the operator will be asked to perform as part of this task likely to change

(a) not at all
(b) some
(c) extensively

type a, b, or c - C

(4) Do you have the subject matter expertise available to help you decompose this task into a series of subtasks? YES

(5) Roughly, how many minutes would it take to decompose this task into 5 to 20 subtasks (whatever would be appropriate)
60

Enter the number of the question to which you would like to change your answer or 'return' for an analysis - 'return'

We recommend against decomposing this task and suggest that you either ask a subject matter expert or simply make a guess.

Figure 23. How to Assign Task Performance Parameters.

Sample User Interface for Aiding the Analyst In Conducting Motion Time Study to Assign Task Performance Parameters

Note: **Bold Entry** indicates Analyst Input

The task that we are considering is as follows:

Task title: Load heat seeking missile
Mission area: Armor
System type: M1 Tank

Since you are using motion-time-study analysis, you must decompose this task into a series of discrete task elements that are at the level of body movements.
You must also have rough estimates of the distances and required accuracies of these movements.

Below are the subtasks that the operator will perform as part of this task that have already been defined:

NOTE: All measurements in inches

Task Element Name	Body Movement Type	Movement Distance	Accuracy
1. **Turn to weapons**	**Rotate torso**	**25**	**4**
2. **Pick up missile**	**Lift arm**	**8**	**5**
3. **Turn to turret**	**Rotate torso**	**15**	**2**
. .	. .		
. .	. .		
. .	. .		
8. **Close chamber**	**Move arm**	**6**	**2**

If you want to ADD, MODIFY, or DELETE, subtasks, enter A, M, or D.
If you want to Review definitions of Body Movement Types, enter R.
If you are Finished with this task definition, enter F.

Enter A, M, D, R, or F - F

Figure 24. Motion Time Study of Task Performance Parameters.

3.2.6 Step 6 - Assign workload values to each operator task (one value for each workload channel [i.e., visual, auditory, cognitive, and psychomotor workload])

Input

External Input - The equipment descriptions presented in the contractor's design document, particularly the description of the human interfaces.

Internal Input - The input to Step 6 will be the task listings (collected in Step 1) and the Task Data File.

Process

The purpose of Step 6 is to assign workload values to each task. During the simulation analysis of operator workload (which will occur in subsequent steps), the analyst will be able to study the demands on operators when they must perform several tasks simultaneously. To determine these collective workload demands, we must first estimate the workload demands on individual tasks.

The technique we are proposing is discussed extensively in Section 3.1. It was developed by ARI and is documented in its application on aviation workload assessment by McCracken and Aldrich (1984). The technique was modified and applied through the use of simulation by Micro Analysis and Design as is documented in Laughery, Drews, Archer, and Kramme (1986). Additionally, the technique is being used by the ARI Field Unit at Fort Rucker. Furthermore, there is basic research which supports these types of techniques for evaluating points of high workload.

Each task will be explored with respect to the amount of workload it requires in each of the following four channels:

1. Visual input workload

2. Auditory input workload

3. Cognitive information processing workload

4. Psychomotor output workload

The above channels are, we believe, fairly self-explanatory with respect to the type of workload implied.

The analysts, sitting at the workstation, will step through each task in the Task Data File and assign workload values to each of the above four channels. They will do this by examining the task description accompanied by the user interface description. Then, they will review four benchmark scales, one for each of the four channels, and select the number which most closely corresponds to the workload in the operator task in question.

As an example, the benchmark scale for visual attention is presented in Table 3.

Table 3

BENCHMARK SCALE FOR VISUAL WORKLOAD

Value:	Task:
1	Monitor, scan, survey
2	Detect movement, change in size, brightness
3	Trace, follow, track
4	Align, aim, orient
5	Discriminate symbols, numbers, words
6	Discriminate based on multiple aspects
7	Read, decipher text, decode

As the analyst progresses through the analysis, he will be able to review and correct previous assignments of task values.

Outputs

The output of Step 6 will be the addition of the individual task workload data to the Task Data File.

Sample User Interfaces

Figure 25 presents a sample user interface for the assignment of workload values for one task. Note that when the analyst is assigning one type of workload, the appropriate benchmark workload scale is provided on the bottom half of the screen.

3.2.7 Step 7 - For each scenario to be studied within each mission, develop descriptions of any additional environmental, threat, or other system conditions which are to be included in the analysis

In some cases, analysts may choose to use the power and flexibility of the simulation tool underlying the WAA to analyze truly closed-loop human operator behavior. For example, to avoid complexity, we will model the consequences of many human decisions as probabilistic events rather than the more complex, rule-based types of responses that really occur. In evaluating operator workload, the effect of this will be minimal. However, some analysts may choose to study these consequences more rigorously. For these individuals, we will provide them with this opportunity through the inclusion of the full power of a simulation modeling system.

Sample User Interface for Aiding the Analyst In Assigning Workload Task Performance Parameters

Note: **Bold Entry** indicates Analyst Input

The task that we are considering is as follows:

Task title: Load heat seeking missile
Mission area: Armor
System type: M1 Tank

The workload channels that you must define are as follows:

Workload Channel		Current value
(v)	Visual	2
(a)	Auditory	0
(c)	Cognitive	undefined
(p)	Psychomotor	5

You are currently working on defining VISUAL workload

Enter v, a, c, or p to select the workload channel that you would like to change or
Enter a number from the workload scale below to reassign the VISUAL workload channel value or
Enter 'return' to complete work on this task.

Enter v, a, c, p, a number, or 'return' - **C**

Figure 25. Assigning Workload Task Performance Parameters.

Through manipulation of this system, the analyst will be able to include detailed models of the hardware and software system, the threat environment, or other aspects of the environment as desired. However, for the analyst not wishing this complexity nor needing to represent the finer aspects of closed-loop human behavior, this step may be skipped.

Input

External input - none

Internal input - The completed Task Data File which will have resulted from performing all of the previous steps.

Process

The basic process of this step will be for the analyst to call up the Micro SAINT Model Development portion of the software. This system is a general purpose modeling system which will, in essence, permit the modeler to construct models of virtually any size and complexity within the constraints of the Micro SAINT modeling system.

The analyst will have the option of two types of "hooks" to the operator workload model. The first type of hook will define how the performance of operator tasks affects these Micro SAINT user created sub-models. For example, the completion of an operator task may be a signal to commence execution of a sub-model associated with the hardware that the operator "actuated" in the task.

The second type of hook that can be defined by the analyst would be how the completion of these sub-model tasks affect the execution of the operator tasks. The only relationships which will be permitted are as follows:

1. An operator task could be delayed until the completion of a sub-model activity (e.g., the representation of the completion of software processing of threat priorities before the operator begins determining if this prioritization was appropriate).

2. The task sequencing logic could be affected.

These restrictions to hooking sub-models to tasks are, we believe, necessary to avoid the danger of the analyst constructing unwieldy and inaccurate sub-system models. By providing more modeling power, we could be providing a tool which, if not fully understood, could easily result in incorrect task sequencing. Again, we believe that this is a reasonable balance for a tool which is designed for addressing operator workload, yet should be as powerful and flexible as possible.

Output

The output of this step will be a series of Micro SAINT simulation models with specific hooks to the operator tasks defined.

Sample User Interfaces

Figure 26 presents a sample user interface for the creation of a "hook" to a Micro SAINT model that will be embedded within an operator workload model. All Micro SAINT user interfaces can be reviewed by examining the Micro SAINT User's Guide (Archer, Drews, and Dahl, 1986).

3.2.8 Step 8 - Exercise the Computer Simulation

From the above seven steps, we will have developed all of the data required to conduct a computer simulation of the operator performing his tasks for the purpose of evaluating points of high operator workload. This simulation will be exercised for each mission and each scenario within a mission. Therefore, the analyst may conduct a number of simulations based on the required number of scenarios identified in Step 4.

Input

External Input - none

Internal Input - The Task Data file with all of the information created in Steps 1, 2, 3, 5, and 6, the Scenario Data File created in Step 4, and the Micro SAINT sub-models created in Step 7.

Process

The process will be very simple. Since the simulation will be a Monte-Carlo Simulation, the analyst will only need to specify the number of times that he or she would like to run the scenario for data collection, the frequency of storing operator workload data (e.g., every second), and on what disk file to store the data. The software will link all tasks, conduct the simulation, and collect the data without further operator input, just as it does with Micro SAINT. The analyst will, simply, tell the system to "GO" and come back several minutes later.

If the analyst chooses, he or she will be able to watch the simulation "run." As with Micro SAINT, several execution modes will be available, from a "let me know when you're done" mode to a "show me every task the operator performs" mode. The latter will be a useful mode for ensuring that the scenario runs as planned.

Sample User Interface for Aiding the Analyst In
Hooking Micro SAINT Models to the Operator Workload Model

Note: **Bold Entry** indicates Analyst Input

---

(1) The name of the Micro SAINT model that you want to hook is
IDTHREAT

(2) A short description of this model is as follows:
This model represents the processes of threat identification by the threat processing computer.

(3) The nature of this hook is a **hold task until this model is complete**

(4) The operator task that will be held until this model is complete is **'Verify correct identification.'**

Enter the field number to change the hook or type R to review the model listed in field 1 above -

Figure 26. Hooking Micro SAINT Models to the Operator Workload Model.

Output

The output of Step 8 will be a series of data files describing, for each run, the collective workload values across all operator tasks at each measurement interval as well as the operator tasks which contributed to that workload. These data will permit all analyses, which will be discussed in Steps 9 and 10, to be conducted.

Samples of User Interfaces

Figure 27 presents a sample user interface which will be presented to the analyst in setting up a simulation run.

3.2.9 Step 9 - Review the output of the computer simulation

Input

External input - Subject matter expertise is desired but not necessary to conduct the data analyses.

Internal input - The data files created during the simulation in Step 8.

Process

Step 9 will be the point at which the analyst has to "make sense" of the data. In this step, the analyst must define high workload and discover points at which this overload seems likely to take place.

The process will involve two distinct substeps, 1) defining operator overload and 2) reviewing the data. Let us discuss these steps individually.

Defining operator overload - Using the proposed methodology, the analysts can define points of operator overload in many ways. They will have two basic questions to address - 1) what are the relationships among the workload variables for each workload channel (visual, auditory, cognitive, and psychomotor) and 2) what is the acceptable workload "window" at different points in the scenario. For both defining overload relationships and window size, the system will include several default definitions. This will permit the analyst who does not want or feel qualified to make these judgments to use reasonable values. These values will be set based on research findings from ongoing research at Ft. Rucker and being planned by the Canadian Ministry of Defense.

Sample User Interface for Aiding the Analyst In Setting Up a Simulation Run of the Operator Workload Model

Note: **Bold Entry** indicates Analyst Input

---

(1) The operator workload model that you will be running is titled **M1 Tank - one on one, stationary**

(2) This model will be run for **10** trials

(3) The data will be stored on the file **M1 RUN01**

(4) Data will be collected every simulated **.5 seconds**

Enter the field number to change the above information or enter 'GO' to start the simulation - GO

Figure 27. Setting Up a Simulation Run.

During the simulation, the workload demands across all tasks being performed simultaneously will be summed within each channel (e.g., two tasks requiring 3 and 2 units of visual workload will result in a cumulative demand of 3+2=5 units of visual workload). However, the simulation will not inherently define the values of these workload values which represent "too much workload." The analyst will be given the option of using boolean relationships to define these points. For example, the analyst could define overload as "points in which any of the workload channels exceed a value of 8." Alternately, the analyst could append to that definition the following "... or all of the workload channels summed exceeds 16." In practice, the analyst may wish to review the data using several different definitions of "operator overload" to evaluate the sensitivity of his predictions about overload to the definition used.

Second, it is reasonable to study workload looking at a window during which the operator could "spread out" his workload. For example, even though two tasks are being performed simultaneously at a given instant in the simulation, practically, the analyst may spread them out over a period of several seconds, assuming that in that several second "window" there was a point of reduced operator workload. The analyst may define the length of that window in time units. To further complicate matters, the length of the window may be different at different points in the mission. At points where immediate operator response is required (e.g., dealing with an incoming threat), there may be no window. At other points, the window may be very wide. The analyst will have the option of defining both window sizes and mission periods that the window size is in effect. "Mission periods" will be defined by either mission times (e.g., "at time 0 through 300 seconds, the window is three seconds wide, thereafter it's one second wide") or tasks which drive window length (e.g., "window size is three seconds except when the operator is engaging in threat management, then it's one second wide."). A "mission times" definition is mission specific and, therefore, every simulated mission will need to be explored individually. In using tasks to define window length, the analyst will be able to develop general definitions which are applicable across all scenarios and missions.

Again, the analyst may wish to study several definitions to explore the effect on overload predictions to his definition of workload windows.

<u>Reviewing the Data</u> - Once the analyst creates these relationships and windows defining operator overload, the analyst will need to identify the scenarios to analyze. Then, the analyst will be given the option of reviewing the data manually or receiving summary reports.

Manual review of the data will involve starting the analysis and then, every time a point of operator overload is encountered in one of the scenarios being reviewed, the following information will be presented to the analyst:

1. The simulated mission time

2. The operator tasks which are currently active and their individual workload demands

3. The cumulative workload demands

4. The current definition of operator overload being employed (relationships and window size)

At this point, the analyst may declare this situation as truly representing overload or not representing overload.

If the analyst only desires summary findings for each scenario, the analysis will compute all points at which overload occurred. Then, it will present these as a percentage of mission time that the operator was overloaded. Additionally, the analysis will present the operator with the opportunity to review nine graphical presentations on the display or in hard copy. These presentations will present 1) operator workload in each of the four workload channels, 2) histograms representing the frequency of workload levels within each of the four channels, and 3) the points at which operator overload occurred within a mission. Examples of each of these nine analyses are presented in Figures 28 through 36.

Output

The output of Step 9 will be a series of times in each of the scenarios studied where operator overload is expected to occur. This will be in the form of hard copy printouts describing the information discussed in the previous subsection.

Sample User Interfaces

Figure 37 presents a sample user interface for defining the relationships which constitute operator overload. Figure 38 presents a sample user interface for defining workload window sizes. Figure 39 presents a sample user interface for the analyst during manual review of the data where he must determine whether this point represents operator overload.

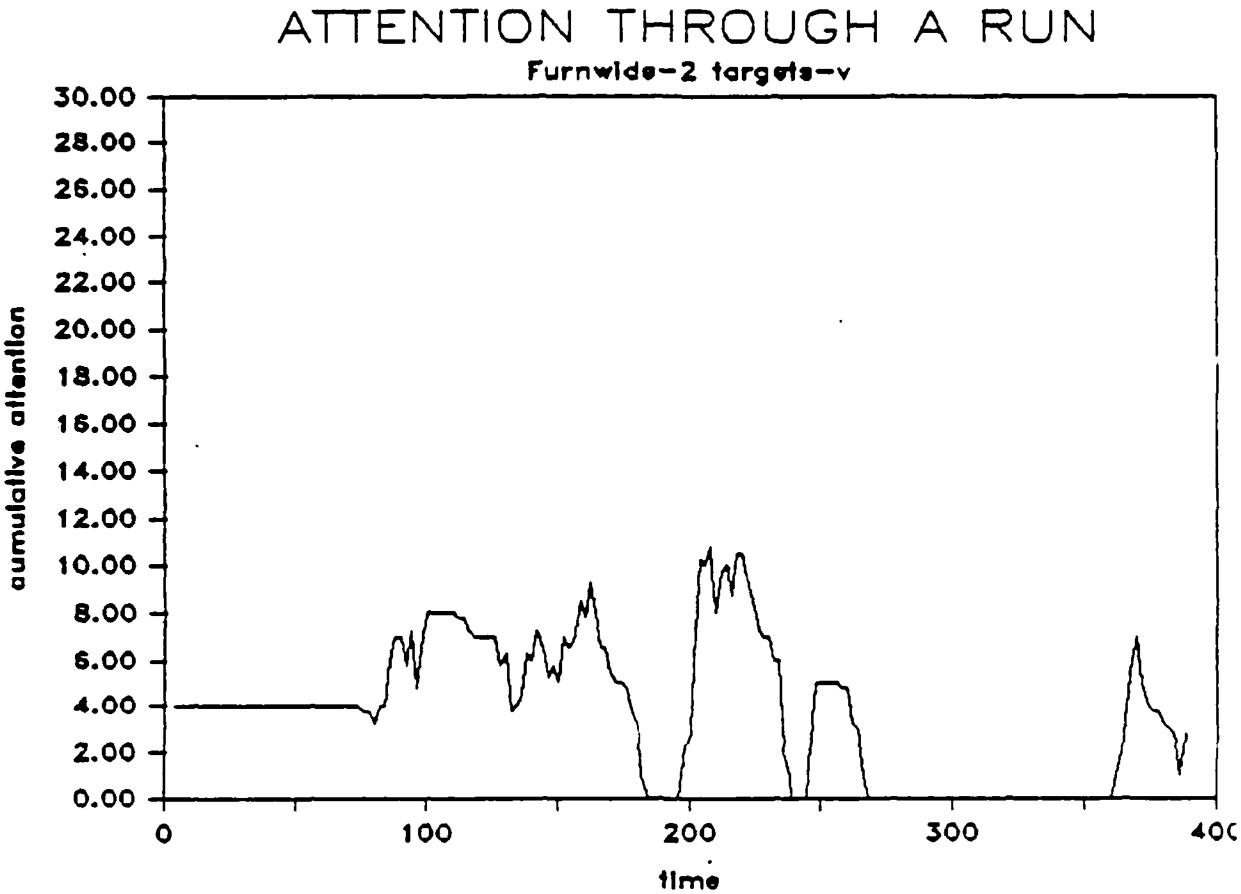

Figure 28. Visual Workload Throughout a Simulated Mission.

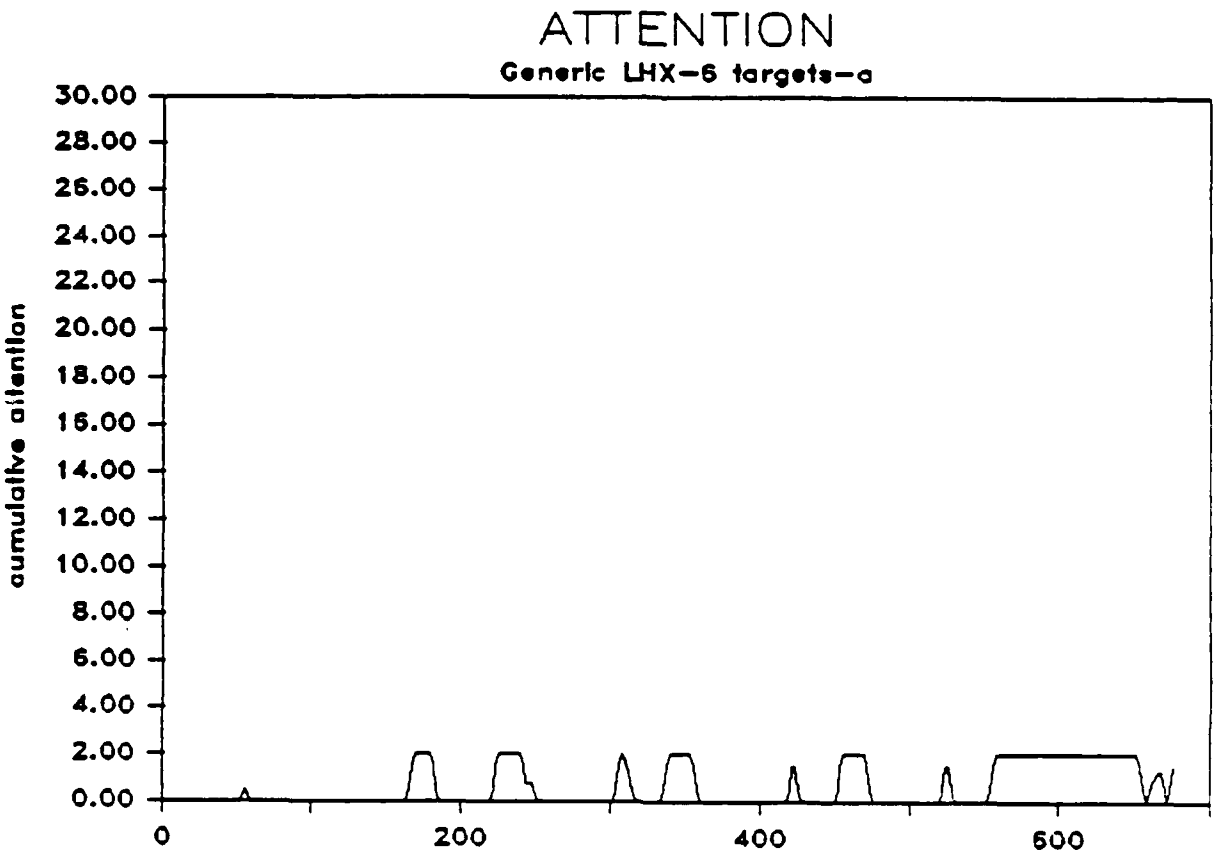

Figure 29. Auditory Workload Throughout a Simulated Mission.

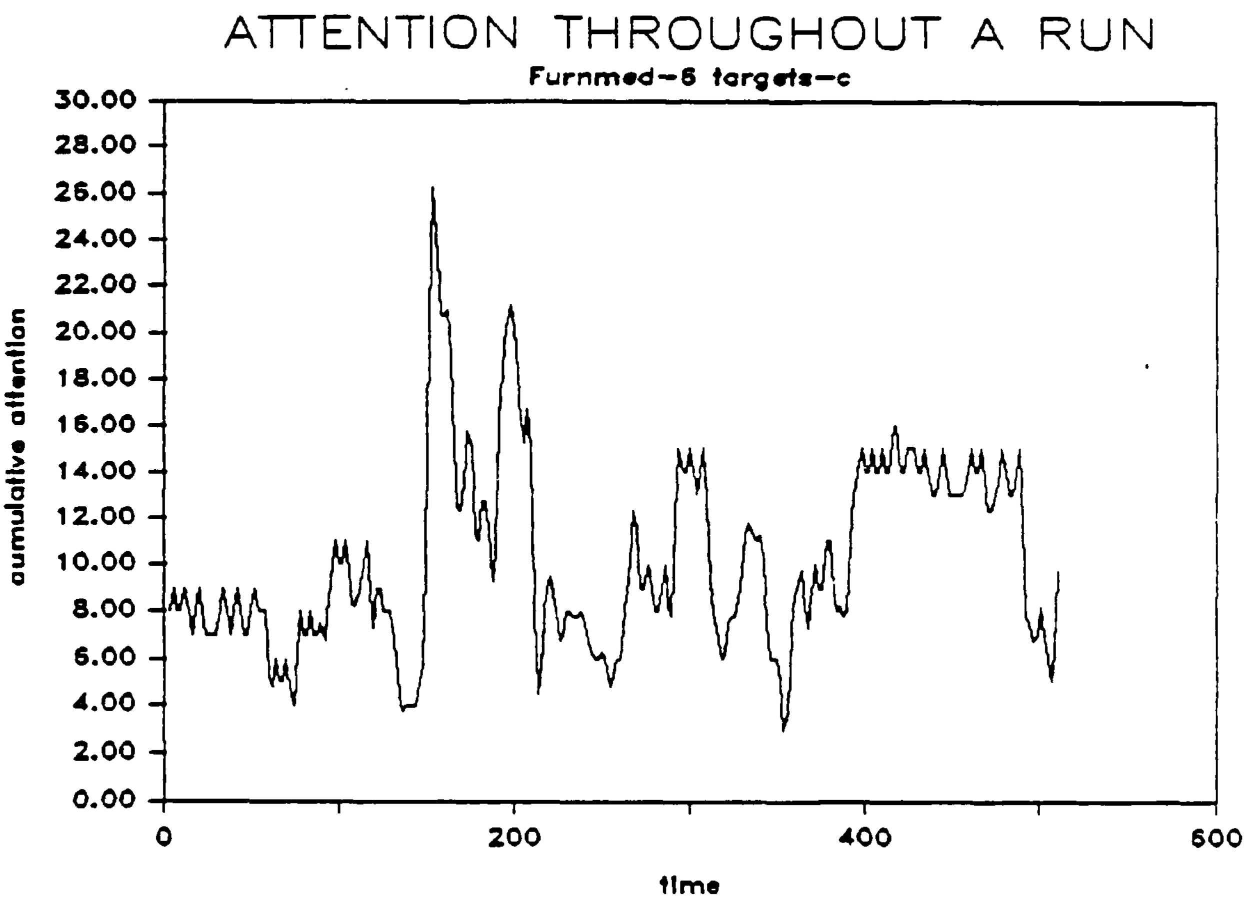

Figure 30. Cognitive Workload Throughout a Simulated Mission.

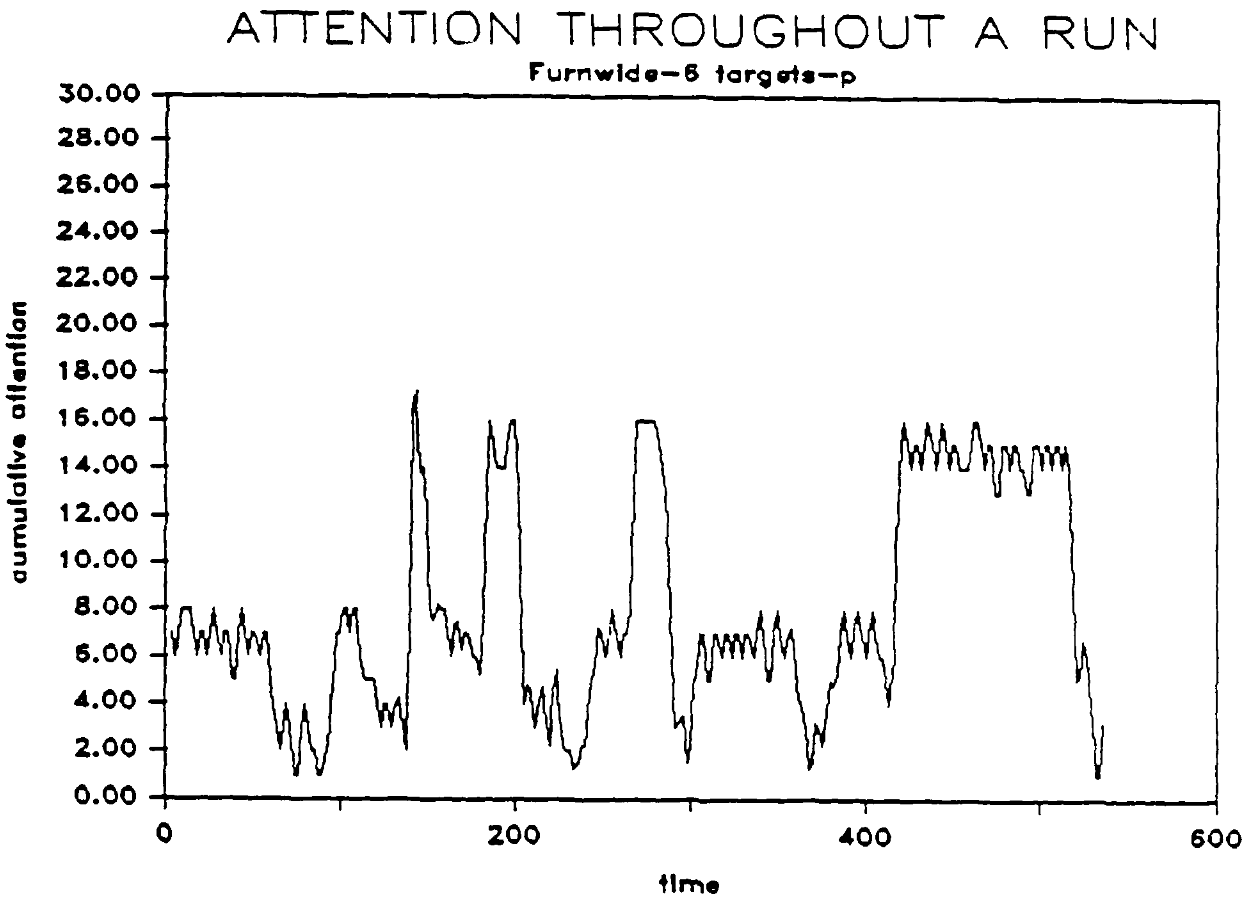

Figure 31. Psychomotor Workload Throughout a Simulated Mission.

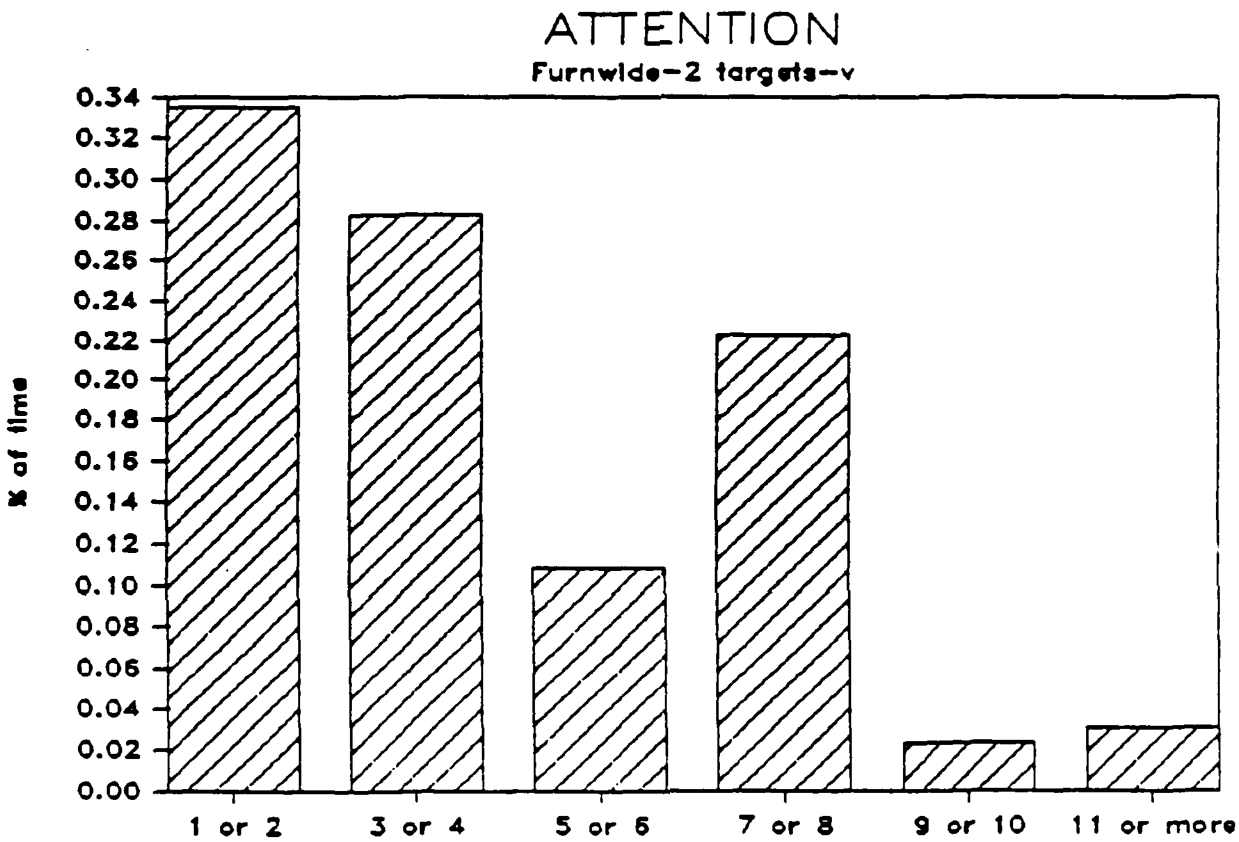

Figure 32. Histogram of Visual Workload Throughout a Mission.

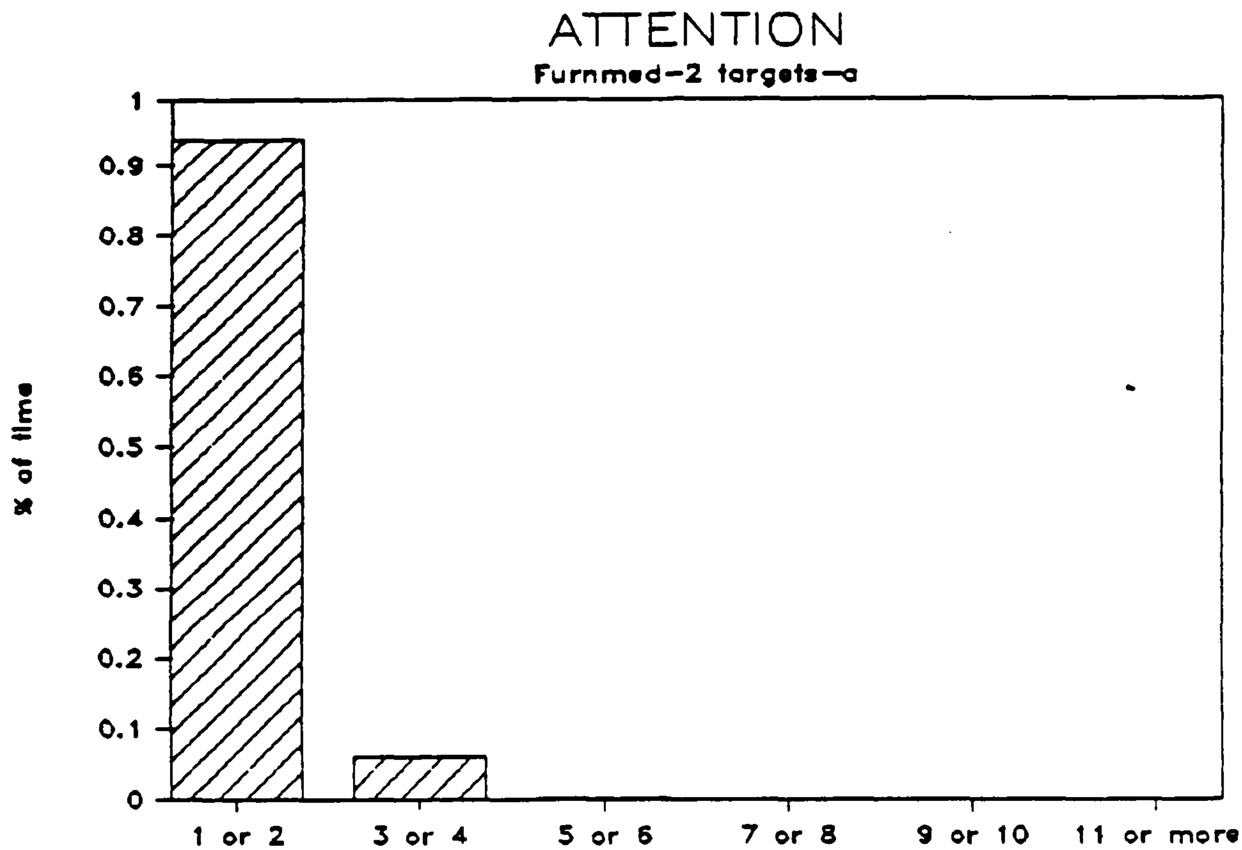

Figure 33. Histogram of Auditory Workload Throughout a Mission.

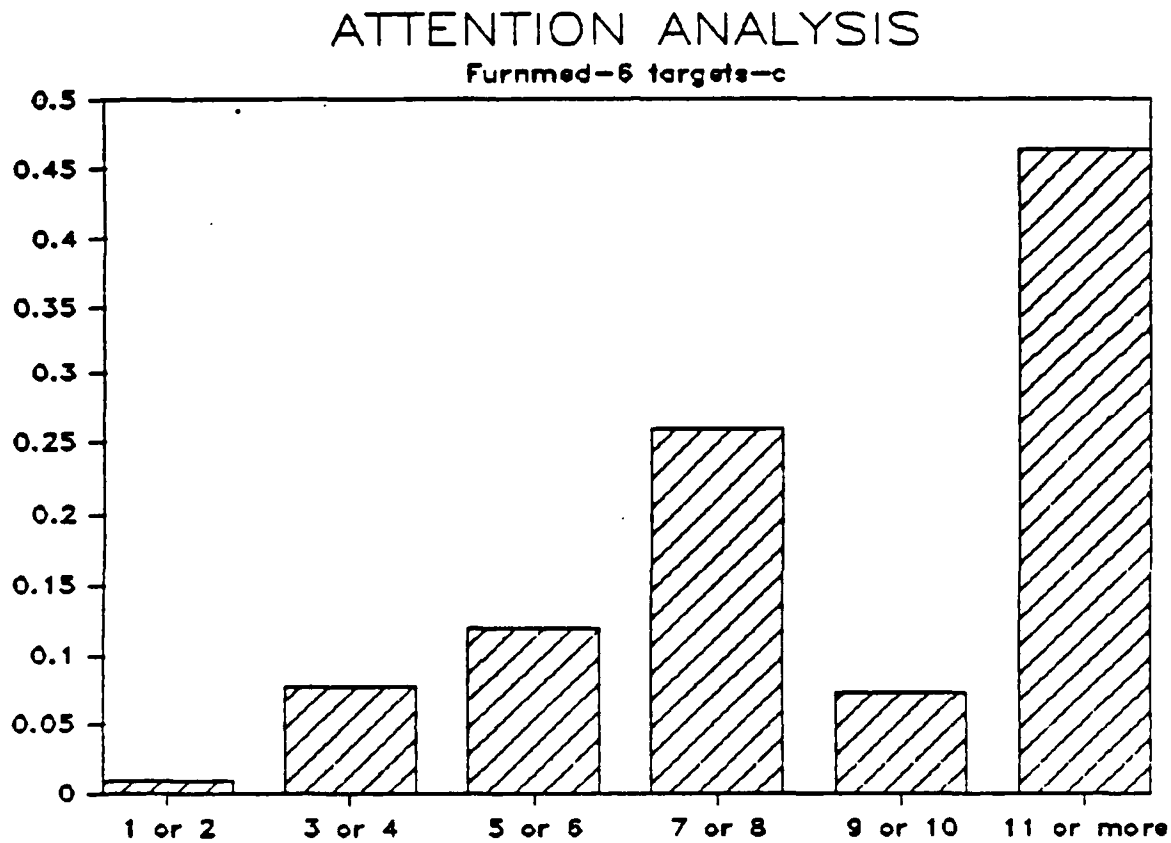

Figure 34. Histogram of Cognitive Workload Throughout a Mission.

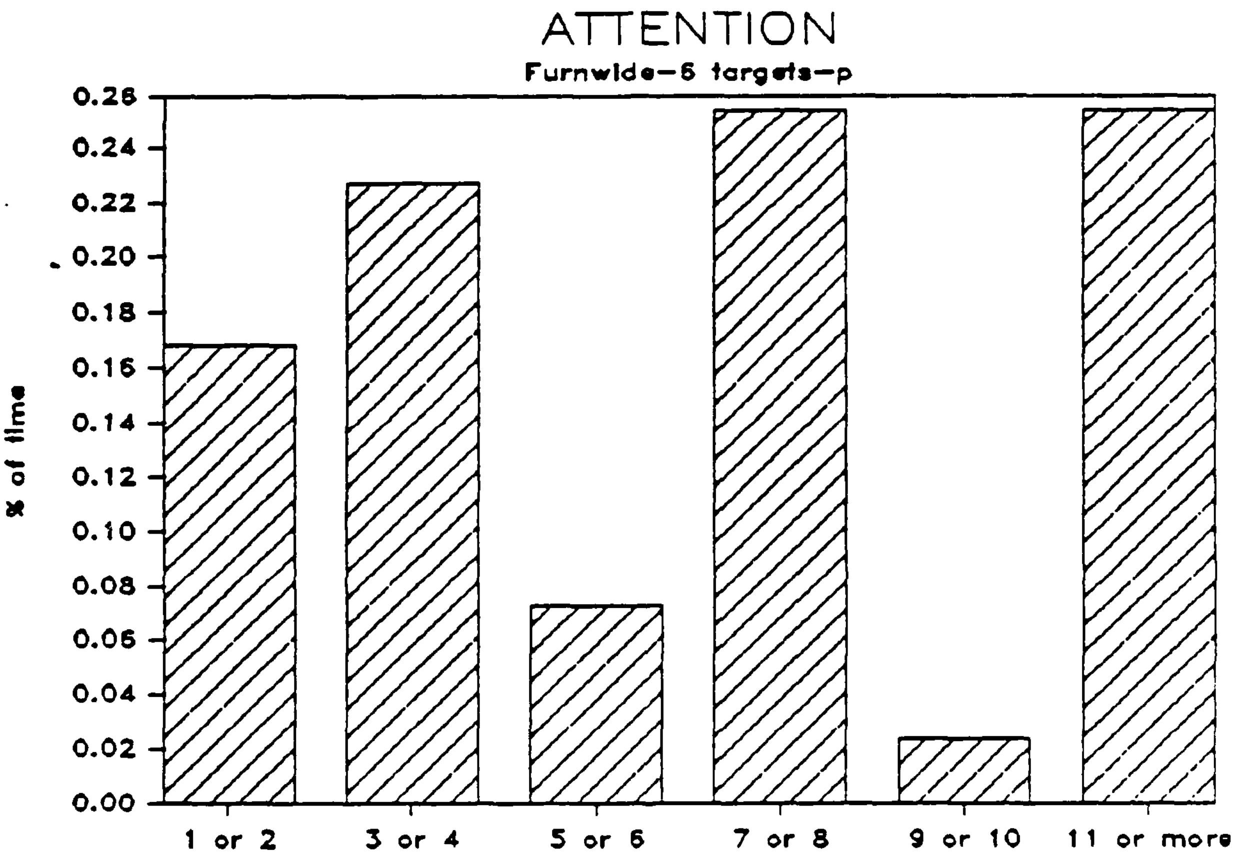

Figure 35. Histogram of Psychomotor Workload Throughout a Mission.

Sample Description of Points at Which Overload Occurred

```
            SUMMARY WORKLOAD ANALYSIS FOR JOB "TANK COMMANDER"

Note:       The following definition of operator overload was used in
            this analysis:
                 V+A+C+P GREATER THAN 15 OR (V GREATER THAN 10 OR A
                 GREATER THAN 10 OR C GREATER THAN 10 OR P GREATER
                 THAN 10)
            and the following tasks were not considered in computing
            workload values (i.e., they were treated as though they
            were performed by another operator)"
                 NONE - ALL TASKS INCLUDED

Summary:

     Operator was in an overload situation 12% of the time.

     The following tasks were being performed in over 50% of these
     overload situations:
          NONE

     The following tasks were being performed in between 25% and
     50% of these overload situations:

          VISUALLY MONITOR OUTSIDE THE TANK

     The following tasks were being performed in less than 25% of
     these overload situations:

          MONITOR ROTATION OF TURRET
          ISSUE "FIRE" COMMAND
               .    .    .
               .    .    .
               .    .    .

Would you like to reconduct the workload analysis under the
assumption that some of the tasks were reallocated?  Y

What task(s) would you like to treat as reallocated?  (Note: this
analysis should be considered as preliminary - a proper
reallocation of tasks and an associated analysis must be performed
before finalizing results:
```

Visually monitor outside the tank

Figure 36. Points of Operator Overload.

Sample User Interface for Defining Operator Overload

Note: **Bold Entry** indicates Analyst Input

Note: In defining operator overload you may use the following four variables:

V (for visual attention)
A (for auditory attention)
C (for cognitive attention)
P (for psychomotor attention)

and you can use the following logical relationships

GREATER THAN
LESS THAN
EQUAL TO
AND
OR

and you can use the following mathematical relationships:

+ (addition)
- (subtraction)
* (multiplication)
/ (division)

The current definition of overload is as follows:

(1) **V+A+C+P GREATER THAN 15 OR (V GREATER THAN 10 OR A GREATER THAN 10 OR C GREATER THAN 10 OR P GREATER THAN 10)**

Enter 1 to change the definition of operator overload
'D' to use default definitions of overload

Figure 37. Defining Operator Overload.

Sample User Interface for Defining Operator Workload Window Size

---

```
The Window Size is currently set as follows:

(1)  2 seconds during the scenario

(2)  Except when the following tasks are executing:

               Task title          Window size

          1.  Change position                   6 seconds
          2.  Identify incoming threat          1 second

(3)  And except during the following scenario times

               Time Range          Window size

               NONE DEFINED

Enter 1 to change the default window size
      2 to change the tasks that define other window sizes
      3 to change time intervals that define other window sizes
      'D' to use the default definition window size
```

Figure 38. Defining Operator Workload Window Size.

Sample Interface Presenting a Point of Operator Overload

Simulation Run Being Reviewed - M60 RUN01

At simulated time 402 seconds by this definition of operator overload

V+A+C+P GREATER THAN 15 OR (V GREATER THAN 10 OR A GREATER THAN 10 OR C GREATER THAN 10 OR P GREATER THAN 10)

Operator overload seems to have occurred in the operator titled LHX PILOT

At that time, the following tasks were being performed by the Tank Commander:

Tasks	Workload Values Visual	Auditory	Cognitive	Psychomotor
Check altimeter	4	0	3	0
Identify incoming threat	5	2	6	0

Should this be stored as a situation of operator overload?
(type yes or no) - NO

Figure 39. A Point of Operator Overload.

3.2.10 Step 10 - Determine acceptability of operator staffing plan and, if discrepancies exist, define the points at which solutions to operator overload must be found

Input

External - Subject matter expertise may be required to make some of the critical decisions regarding overall acceptability.

Internal - The data generated in Step 9.

Process

The WAA will provide the analyst with a set of guidelines to help him make the decision as to the acceptability of the system design. Virtually every system in which a human is involved is going to be one in which the potential for human task overload exists. One can always complicate the scenario to the point at which the human has more work than he can effectively handle. The key questions about the effect of this on the system design's acceptability are the following:

1. Are these points of overload so common that no operator can be expected to reasonably perform all or most of his required activities throughout many segments of the mission?

2. Are points of extreme overload found such that, at these points, the operator is likely to become immediately overwhelmed?

3. Do points of significant overload occur at points where mission success or survivability are in danger?

The first question will be addressed by examining the summary data from the scenarios. If operator overload is occurring in excess of 10% of the mission and average workload throughout a mission is high, then the analyst will be advised to suggest restaffing or redesign of the system.

The second and third questions will be addressed by reviewing the points at which overload occurred. A subject matter expert will probably be very helpful in making the appropriate determinations as to whether the workload is extremely high or whether the mission itself is endangered at that point. If points in the mission are identified that are clear problems, these will be automatically stored in a reports data file.

Outputs

The outputs of this step will be a series of scenario descriptions and points in those scenarios where operator workload was found to be excessive. Additionally, a set of summary statistics on each mission analyzed will be presented (e.g., percentage of time in overload situation, definition of overload, etc.).

When the results of a simulation indicate that the current staffing plan did not produce unacceptable operator workload levels and the system performance requirements have been met, the analyst can obtain a manpower summary report that contains the following data:

- The operator jobs
- The tasks that were assigned to each job
- The number of operators that were required for each job

Sample User Interfaces

Figure 40 illustrates a sample interface summarizing the results of the analysis.

3.2.11 Step 11 - Reallocate tasks to jobs or add operators in a way that would result in successful system operation and acceptable operator workload

Input

External Input - To ensure that any revisions to the allocation of tasks to jobs is reasonable, we will advise the analyst that a subject matter expert should be available. However, the absence of a subject matter expert does not make this analysis impossible.

Also, the system performance requirements identified by the SPREA (Product 1) will be required.

Internal Input - The Task Data File, the Scenario data file, and the results of the simulation will be the primary input to this step.

Sample User Interface Presenting Summary of Workload Findings

---

Scenario - M60 RUN01

Percentage of time that each of the operators was in an overload situation:

Tank Commander - 11%
Gunner - 6%
Loader - 0%
Driver - 0%

Do you want to review a list of tasks for any of the operators that were involved in overload situations? **Yes**

Which Operator? **Tank Commander**

The following tasks were involved in overload situations for the TANK COMMANDER

Task name	Percentage of time that this task was being performed that overload was occurring
Identify target	8%
Lase to target	60%
. .	.
. .	.
. .	.
. .	.

Figure 40. Summary of Workload Analysis Results.

Process

The process of determining how to reallocate tasks to operators will involve the following substeps:

1. Determine whether System Performance Requirements as specified in Product 1 are being met.

2. Determine (from the previous step) the points at which high workload for one operator coincides with low workload for another operator.

3. Reallocate tasks among operators based on the information from substeps 1 and 2 above with due consideration given to control and display accessability constraints.

4. Evaluate new allocation of operator tasks using Steps 4 through 10 (as described in Sections 3.2.1 through 3.2.10).

5. Iterate substeps 1 through 4 above until either an acceptable allocation of operator tasks to jobs is discovered or it becomes clear that at least one more operator is required.

6. If another operator is required, check whether the design will support an additional operator (supportability constraint).

7. If another operator can be added, allocate tasks to the new operator.

8. Iterate substeps 1 through 4 above until either an acceptable allocation of operator tasks to jobs is discovered or it becomes clear that at least one more operator is required.

9. Repeat substeps 6, 7, and 8 above until an acceptable solution is found or it is infeasible to add more operators, thereby rendering the design infeasible within the currently presented personnel and training constraints.

Most of the above steps have been discussed in detail in other parts of this paper. However, let us emphasize some of the salient points.

It is in substep 1 that we ensure that the contractor's design, in essence, meets the design specifications with respect to functions performed by humans. As we noted earlier in this paper,

we are not relying on contractor estimates of human task performance time and accuracy, even if they are provided. Rather, we will estimate these parameters independently. Therefore, it is entirely possible that their design and the associated logical allocation of tasks could result in low operator workload but not minimally acceptable functional performance. For example, a contractor's task analysis may indicate that tasks are performed in series by an operator to minimize workload associated with performing several tasks simultaneously. Based on contractor time estimates, performing tasks serially would still result in acceptable performance. However, in applying this tool, the analyst may determine that the time estimates were low and, therefore, the human took longer to perform the function than the minimally acceptable criteria (defined in Product 1) permitted. This being the case, this allocation of tasks to operators is not acceptable unless an alternative task allocation arrangement can be identified (e.g., assign some of the tasks to other operators and test to ensure that workload is acceptable).

Therefore, in using the WAA to assign tasks to jobs, the analyst must consider whether or not the assignments still result in an acceptable level of human performance of functions. If not, then the allocation of tasks to operators must be reconsidered.

To determine whether human performance satisfies the minimally acceptable performance criteria, the analyst will need to review the outputs of the SPREA (Product 1) and map SPREA tasks to human operator tasks or groups of tasks. This will involve a review of the Product 1 analysis for the system under consideration. Then, the performance criteria defined in this analysis will be compared to the performance estimates obtained from the simulation run conducted in Step 8. If the performance criteria are met, then this does not need to be a consideration in the reallocation of tasks among operators.

In Substep 2, the analyst will be given information to assist him in reallocating tasks. He will be able to review the workload simulation results to determine, for points of high operator overload, whether there were points of low workload for another operator.

In Substep 3, tasks will be reallocated to operators based on the nature of the problems with the current task allocation scheme which were identified in Substeps 1 and 2. The WAA will not provide the analyst with any specific task assignment algorithms. This is a difficult job which will consider a number of interrelated factors, many of which are not amenable to automation. The analyst, with the aid of the analysis tools provided in the Workload Diagnostics Template, will have to make some guesses as to what the appropriate reallocation of tasks among operators might be.

As the analyst is considering reallocating tasks, the WAA will remind him or her of the control and display accessability constraints that must be considered. This will aid the analyst in ensuring that he does not assign tasks to operators when the controls or displays needed to perform that task are not within his reach or view.

Once the analyst has performed the first three substeps, then he will have developed a new "hypothesis" regarding the allocation of tasks to operators (jobs). Substep 4 will be to test this hypothesis by repeating Steps 4 through 10 of the WAA as discussed in the previous sections. This effort will be far less time consuming than the initial analysis since most of the tasks will not change and, even of those which are reallocated, many will not change.

As is the case with many complex systems, the simple "reallocation of tasks" will frequently have many rippling effects. Therefore, the analyst can expect that he may have to try several alternatives until he finds one that is acceptable. This is the intent of Substep 5.

On the other hand, it may be obvious very quickly that there is no alternative which will satisfy both the workload constraints and the system performance criteria. Therefore, to satisfy these constraints, additional operators must be added. In Substep 6, we will ensure that adding an additional operator will <u>not</u> violate the supportability constraint. In other words, the design will support an additional operator.

When an operator is added, then we must reallocate tasks (Substep 7) and rerun the first four substeps of this step to ensure that workload and system performance criteria are adequately addressed. Again, this process is continued until it becomes obvious that another operator must be added (Substep 8).

At some point, it may become obvious that the system cannot support the number of operators required to meet the system performance criteria without creating excessive operator workload. At this time, the work of the WAA is completed. This in <u>not</u> to say that the design is infeasible with respect to MANPRINT issues. Rather, it becomes a question of whether these performance and workload criteria could be met by using a more select operator population or by providing more training. These questions are in the domain of Product 6.

On the other hand, at some point an acceptable allocation of tasks to operators may be found. This is not to say that this definition of jobs, tasks per job, and numbers per job necessarily represents a feasible solution from a manpower perspective. We have not considered the overall manpower constraint (the output of Product 2) in this analysis. In fact, while the system design may

support more operators, the Army's manpower availability may not. However, we <u>will</u> have found that, given adequate manpower, the system can be used successfully.

Outputs

At the completion of this step, regardless of the outcome, the analyst will call out the Reports Generation Template. This software will then print out a summary of job titles, numbers of each job per system, and tasks per job. The analyst will be presented with the opportunity for generating more detailed reports describing task performance parameters, percentage utilization of each task, and a host of other potentially interesting findings.

User Interfaces

The user interfaces for these tasks will be the same user interfaces which were presented for the creation of Task and Scenario Data Files accordingly.

3.2.12 Summary of the WAA Process

The WAA will begin with a description of the operator(s) activities provided by the contractor, from predecessor or comparable existing systems, or by the output of Product 1. Task performance parameters (speed and accuracy) will be estimated using a variety of potential methods depending upon the time available to conduct this analysis and other factors. Additionally, workload estimates for tasks will be derived based on task and operator interface descriptions.

The missions and scenarios selected for study will be those anticipated to require high operator workload. The scenarios will be described in a manner that will permit their incorporation into computer models. No computer programming will be required.

Once the operator tasks and scenario are defined, a computer model will be run. No computer expertise on the part of the analyst will be required to create or run this simulation.

The analyst will review data from the simulation to determine points of operator overload as he or she chooses to define it. If points of operator overload occur too frequently, then the analyst, if he chooses to, will be able to reallocate tasks across operators or add operators and then rerun the simulation to determine if operator workload is acceptable. As he or she does this, the analyst will ensure that task reallocations do not violate the control and display accessibility constraint and that the addition of operators does not violate the supportability constraint.

The analyst will continue to use this hypothesis testing approach to determine a configuration of operator jobs, tasks per job, and numbers of people per job that will meet system performance requirements, not violate manpower constraints, and not cause any of the operators to experience excessive overload.

3.3 WAA SOFTWARE ELEMENTS

In this section we will present preliminary software designs and data sources for the software elements which were defined in Section 3.1.4. These elements were grouped into the following four categories:

1. The Templates for users to create Files and analyze results of the analyses

2. The Libraries including historical information which the analyst can use to construct his analysis

3. The Files which the user creates representing the operator's performance within a mission

4. The Models to run the operator workload simulation and generate data for analysis

Over all of the software elements will be an Applications Manager which will be, essentially, the operating system in which the analyst works. Within the Applications Manager will be a Report Generator. The Report Generator will allow the preparation of reports which detail the operator tasks, task sequencing, scenario information, results of a simulation run, and any other pertinent information associated with each scenario that the analyst has created.

Let us now discuss in some detail each of these software elements in some detail. Each discussion will be subdivided first into the specific software elements that were identified in Section 3.1.3. Then, for each of these, we will discuss the basic software architecture and the sources of data (where appropriate). For software elements which are programs (the Templates and Models), we will present high-level flow charts. For software elements which are data (the Libraries and Data Files), we will define the information which will be stored in the data base and the sources of these data (in the case of the libraries).

3.3.1 The Templates

Function and task definition template

This program will lead the analyst through the creation of lists of operator functions and tasks for the system being studied.

It will include definition of task performance parameters, workload requirements, and limitations on task performance (e.g., the availability of resources, the completion of other tasks). In fact, it will lead the analyst through the performance of Steps 2, 3, 4, and 5 as of the operator workload analysis process as defined in Sections 3.2.2, 3.2.3, 3.2.4, and 3.2.5.

Figure 41 presents a high level flow chart for the Function and task definition template. Figure 42 presents a more detailed breakdown of the portion of the template focused on defining crew positions and tasks that each crew member performs. Figure 43 presents a flowchart for the task workload parameter input. In the next Section, we will discuss the portion of this template associated with task performance parameter estimation.

Please note that all user inputs associated with sample interfaces which were presented in Section 3.2 are duly indicated.

The task performance parameter estimation template

This program will lead the analyst through the estimation of task performance parameters including task performance time, standard deviation of performance, and the probability of making an error. This software element will be embedded in the function and task definition template discussed above, but it is of sufficient importance and complexity to distinguish for the purposes of discussion in this paper.

We are using the following three approaches to assisting the analyst in defining task performance parameters:

1. An analysis of comparable systems which are currently fielded in the Army and for which operator performance data reside in the Task Library

2. Subject matter expert estimates based on the new system's description and a background with similar fielded systems

3. Task decomposition and analysis whereby the analyst must decompose the overall operator task into task elements and synthesize overall task time by estimating the task element times

Figure 44 presents a flowchart of the overall process of this template. Figures 45, 46, and 47 present flowcharts for the estimation of task performance parameters by the above three methods.

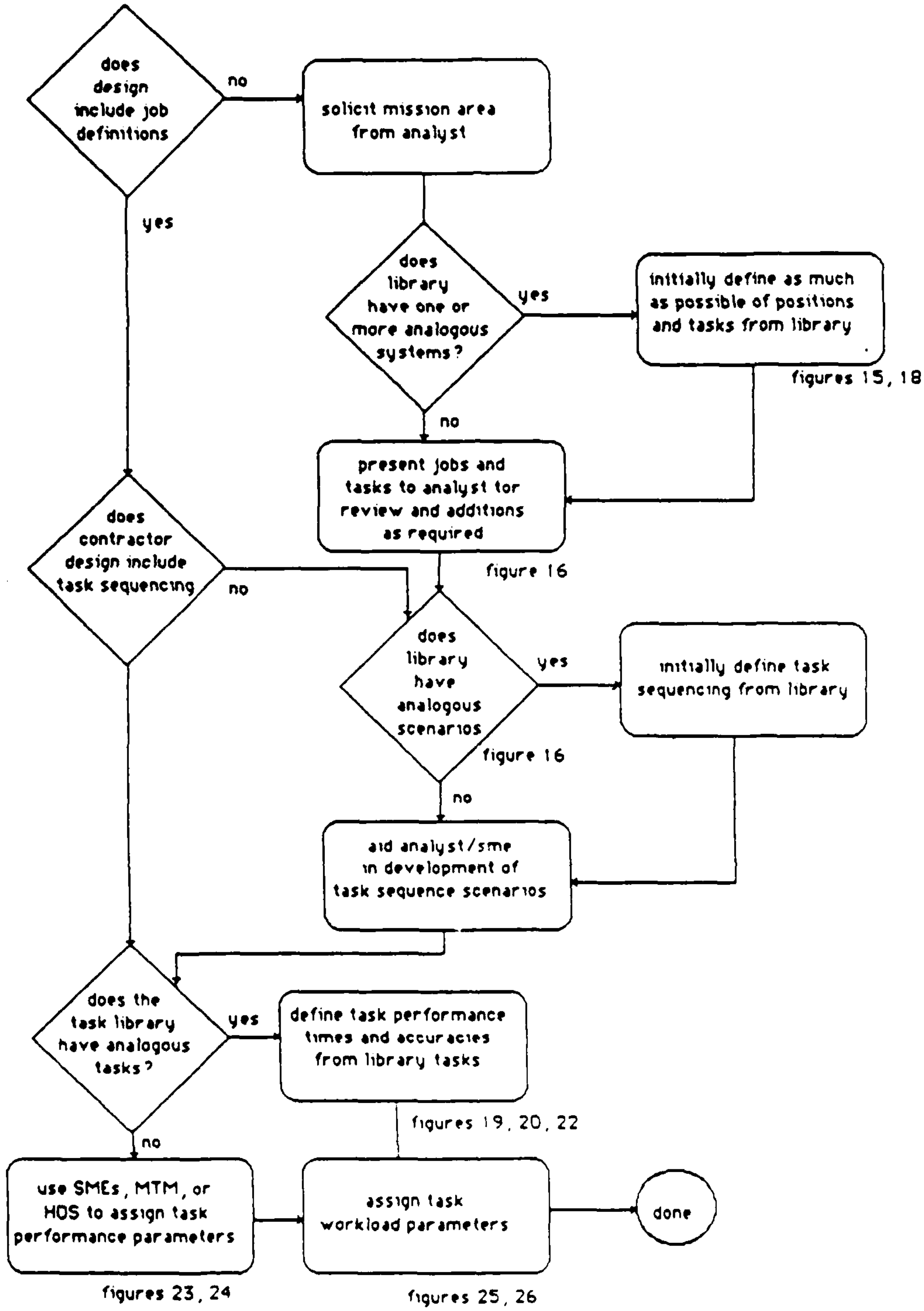

Figure 41. High Level Flowchart for the Function and Task Definition Template

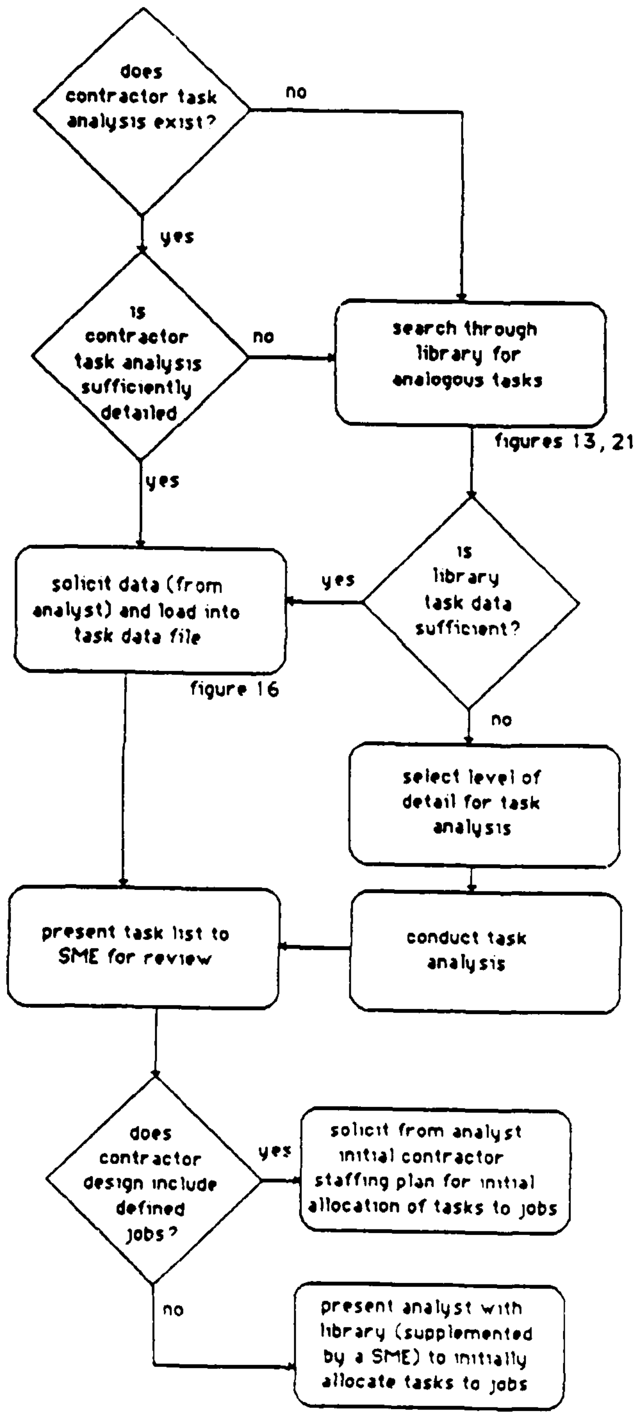

Figure 42. Detailed Breakdown of the Template Focused on Defining Crew Positions

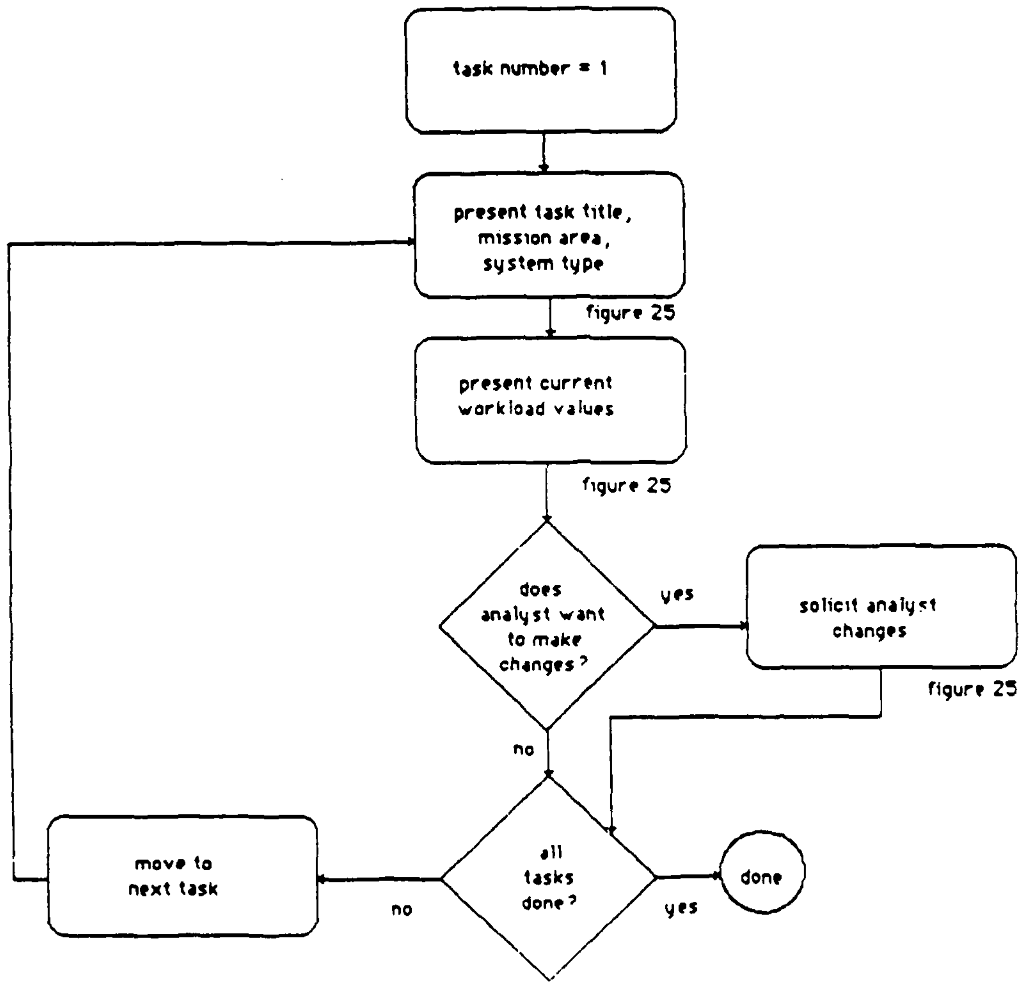

Figure 43. Flowchart for the Task Workload Parameter Input

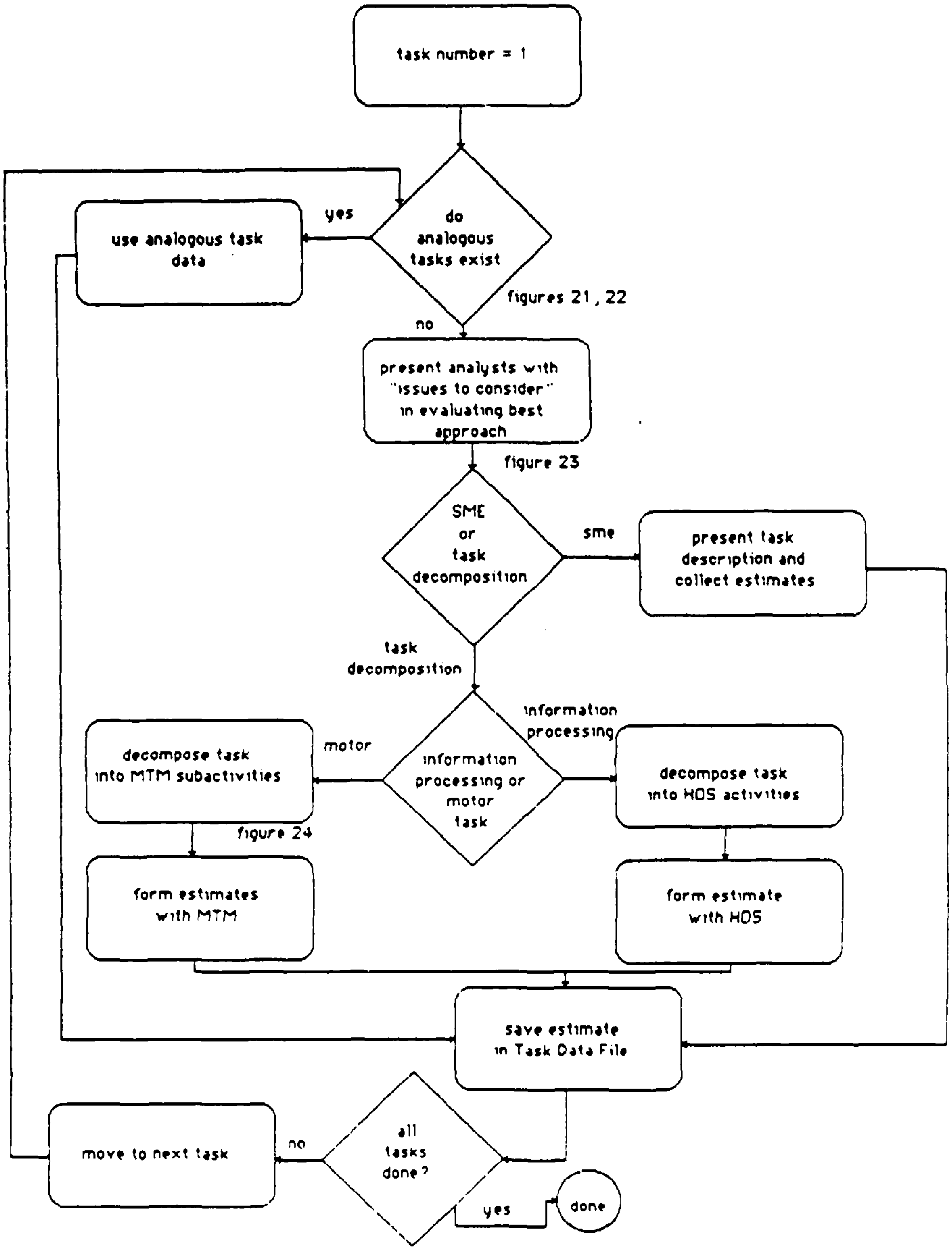

Figure 44. Flowchart of the Overall Process of Task Parameter Estimation Template

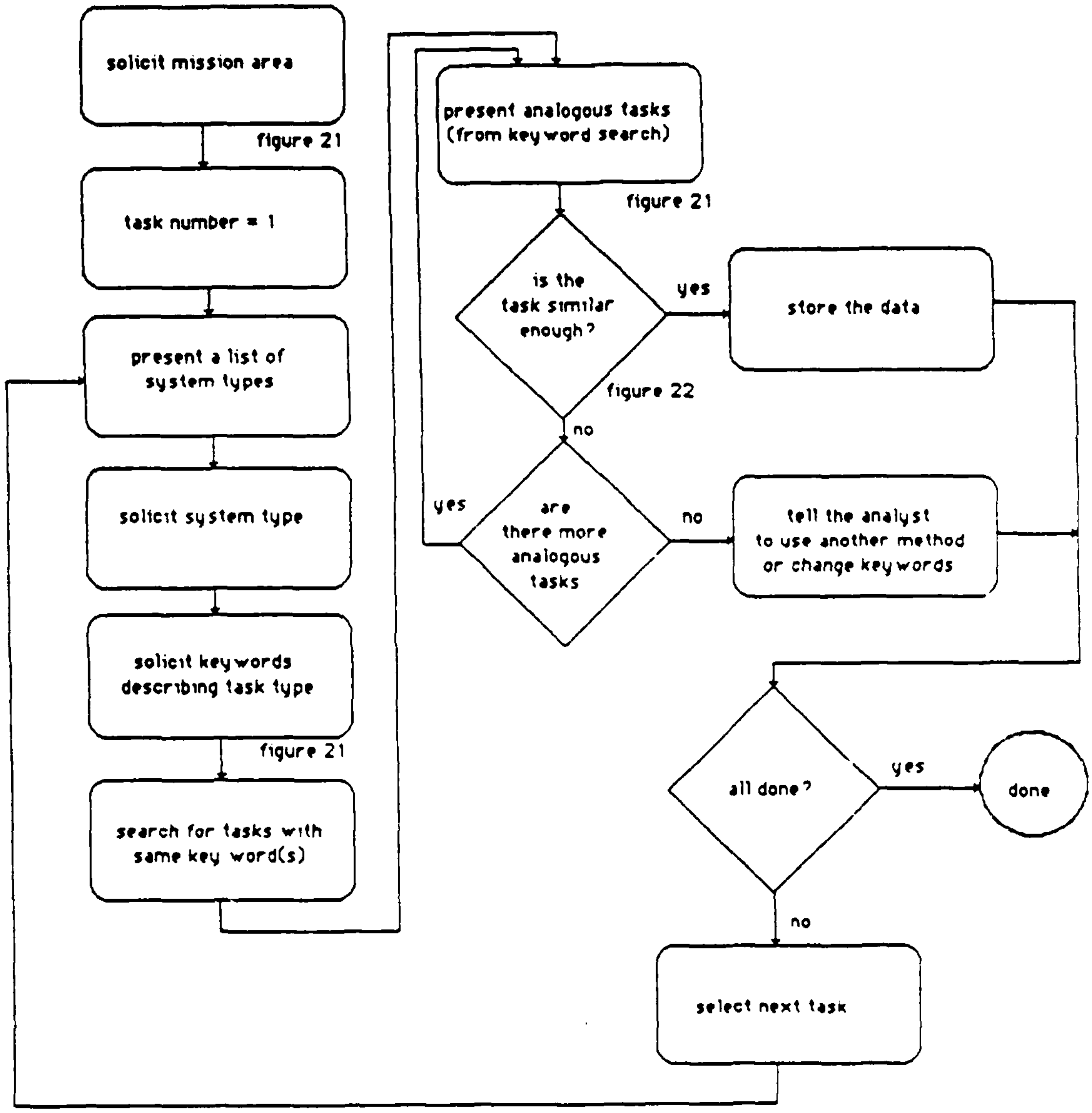

Figure 45. Flowchart of the Overall Process of Task Parameter Estimation via Comparable Systems Template

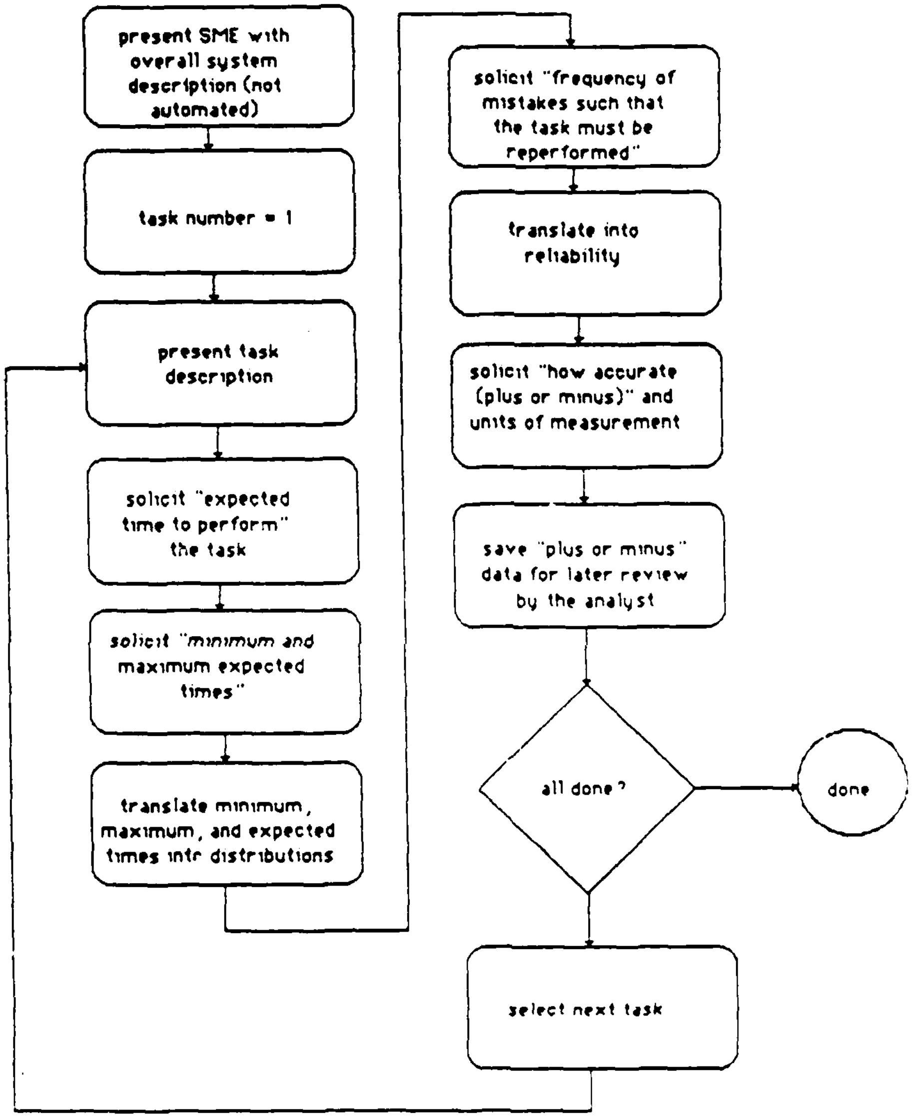

Figure 46. Flowchart of the Overall Process of Task Parameter Estimation via Subject Matter Experts Template

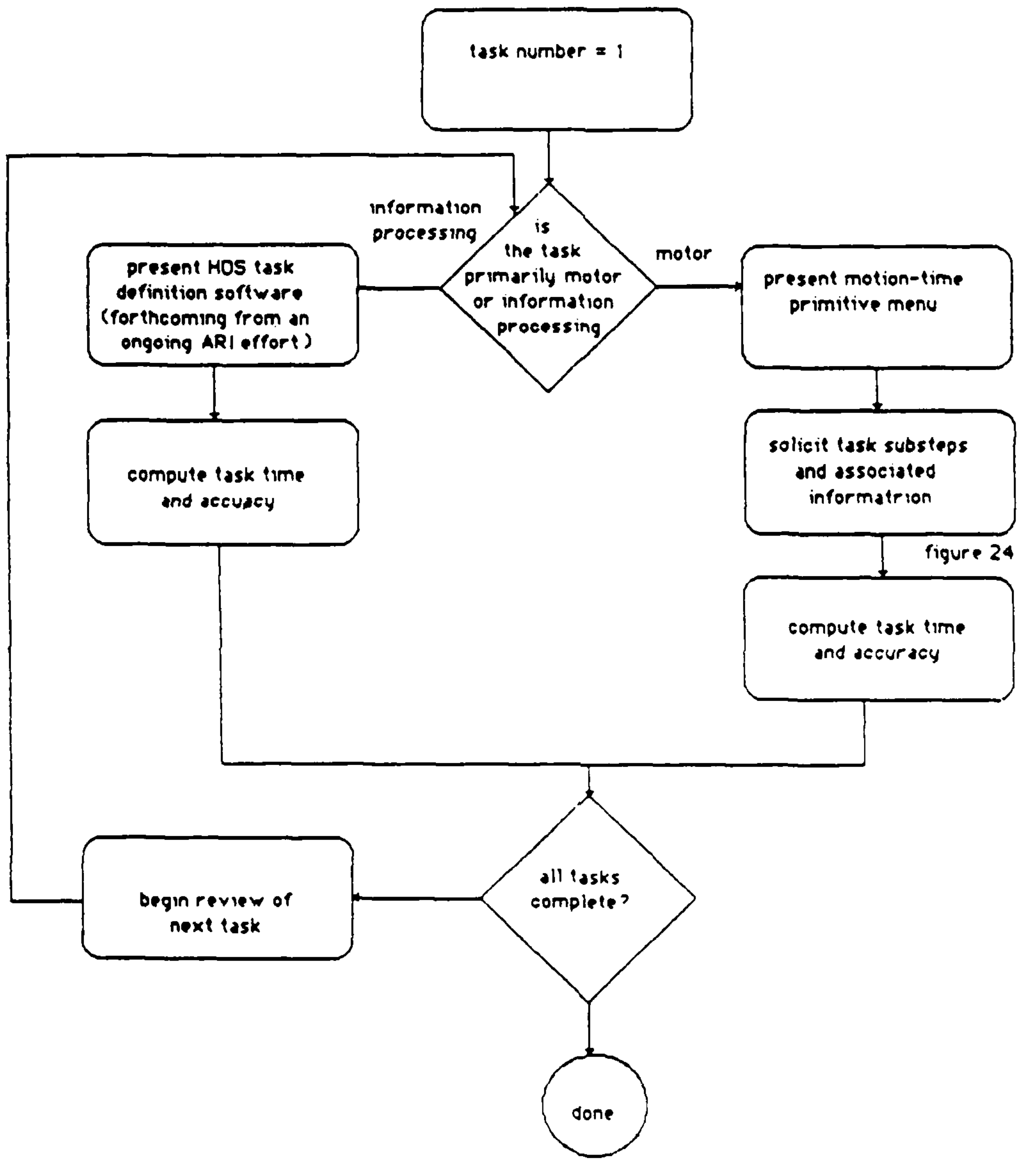

Figure 47. Flowchart of the Overall Process of Task Parameter Estimation via Decomposition Template

The scenario creation template

This program will lead the analyst through the creation of scenarios under which the system will be studied. It will involve the development of sequencing relationships among operator tasks and the addition of non-operator tasks (e.g., threat models) should these system elements need to be modeled.

In constructing a scenario, the template will lead the analyst through a series of methods for selecting and defining scenarios. The overall flowchart for this template is presented in Figure 48. Figure 49 presents a flowchart for the search through the Scenario Library for similar scenarios. Figure 50 presents a flowchart for the definition of a new scenario.

The workload diagnostics decision aid template

This program will assist the analyst in defining high workload for the simulation data analysis. Ultimately, it will assist the analyst in determining whether workload was excessive.

Figure 51 presents a flowchart for the development of definitions of operator overload. Figure 52 presents a flowchart for the review of the results of the workload analysis data.

Task Performance Requirement Template

This template will lead the analyst through the process of determining task performance requirements for individual tasks to assure that system performance is satisfactory. It will be used when the analyst determines that the current task performance parameters and allocation of tasks across operators results in unacceptably high workload.

The focus of this template will not be to estimate task performance for a given design (this is the job of the Task Performance Parameter Estimation Template). Rather, this template will lead the analyst through the process of finding acceptable task allocations and performance levels from an operator workload perspective for the design to satisfy the performance requirements (identified in Product 1) while staying within the manpower constraints (identified in Product 2). This template will be used in Step 10 as discussed in Section 3.2.10.

This template will be largely a decision aid since the actual process of revising task performance requirements or reallocating tasks across operators will be done with the Function and Task Definition Template or the Scenario Creation Template. The Task Performance Requirements Template will lead the analyst through the process of 1) determining the appropriate way to change task requirements (i.e., modify operator task performances or reallocate tasks), 2) considering the various

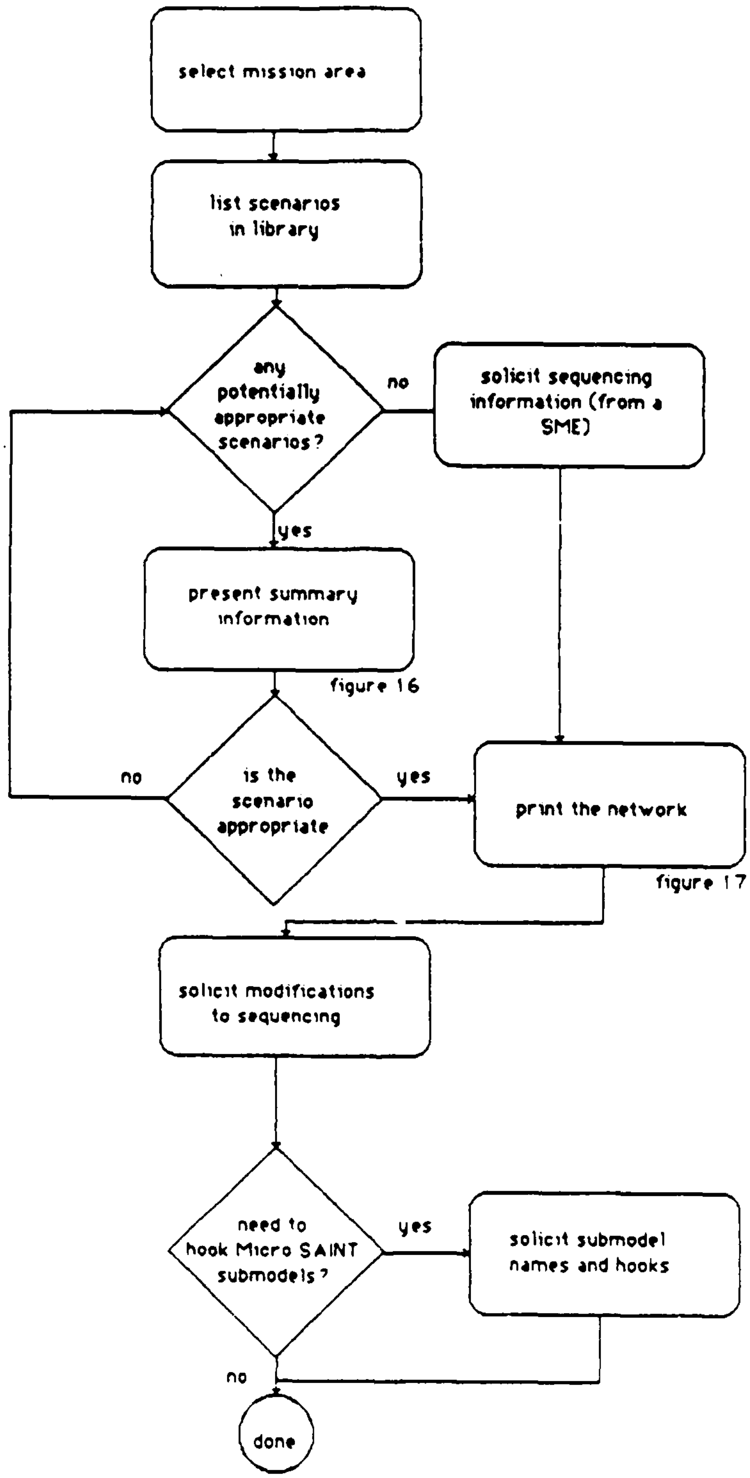

Figure 48. Flowchart for Scenario Definition Template

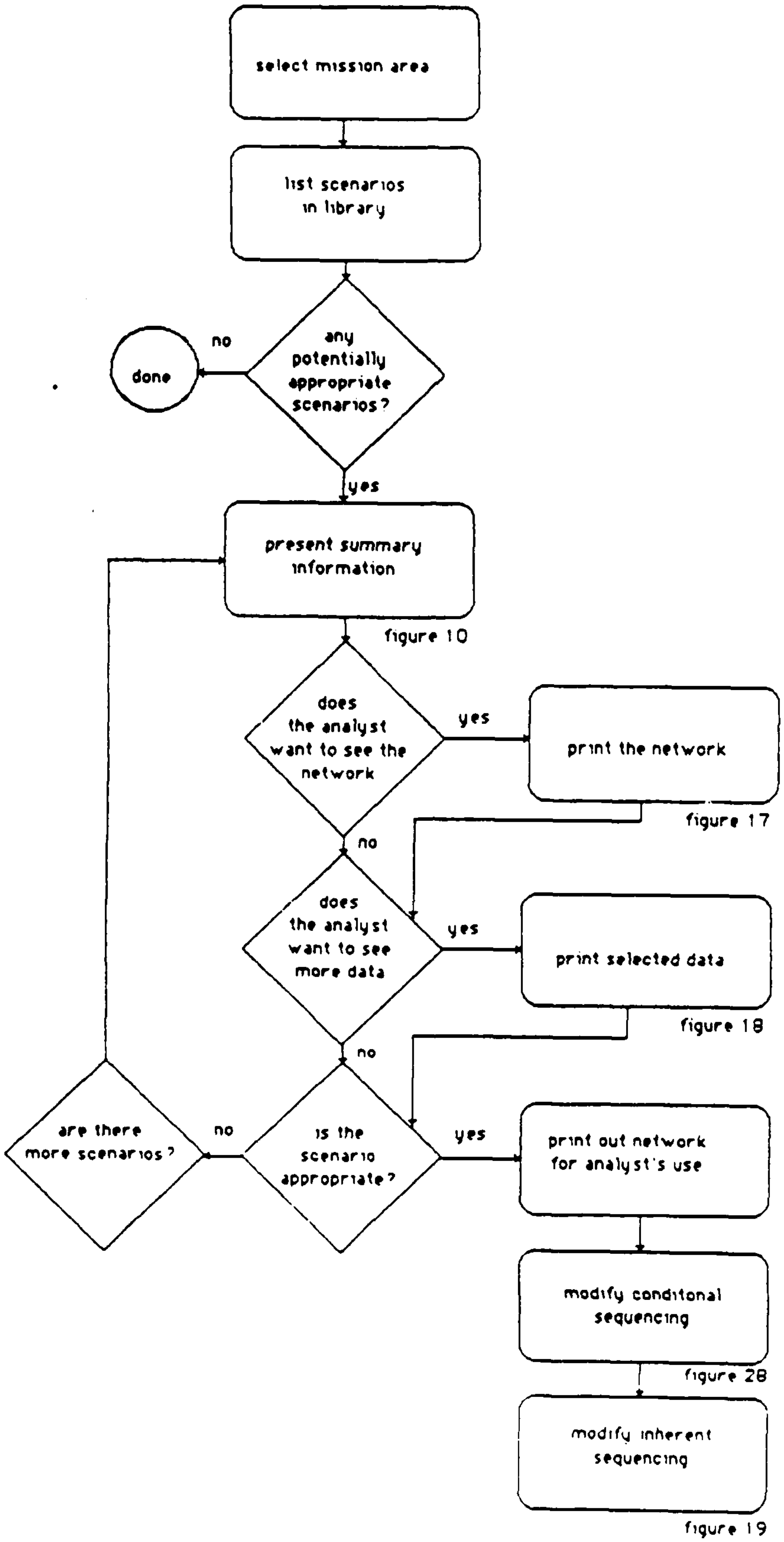

Figure 49. Flowchart for Search Through Scenario Library

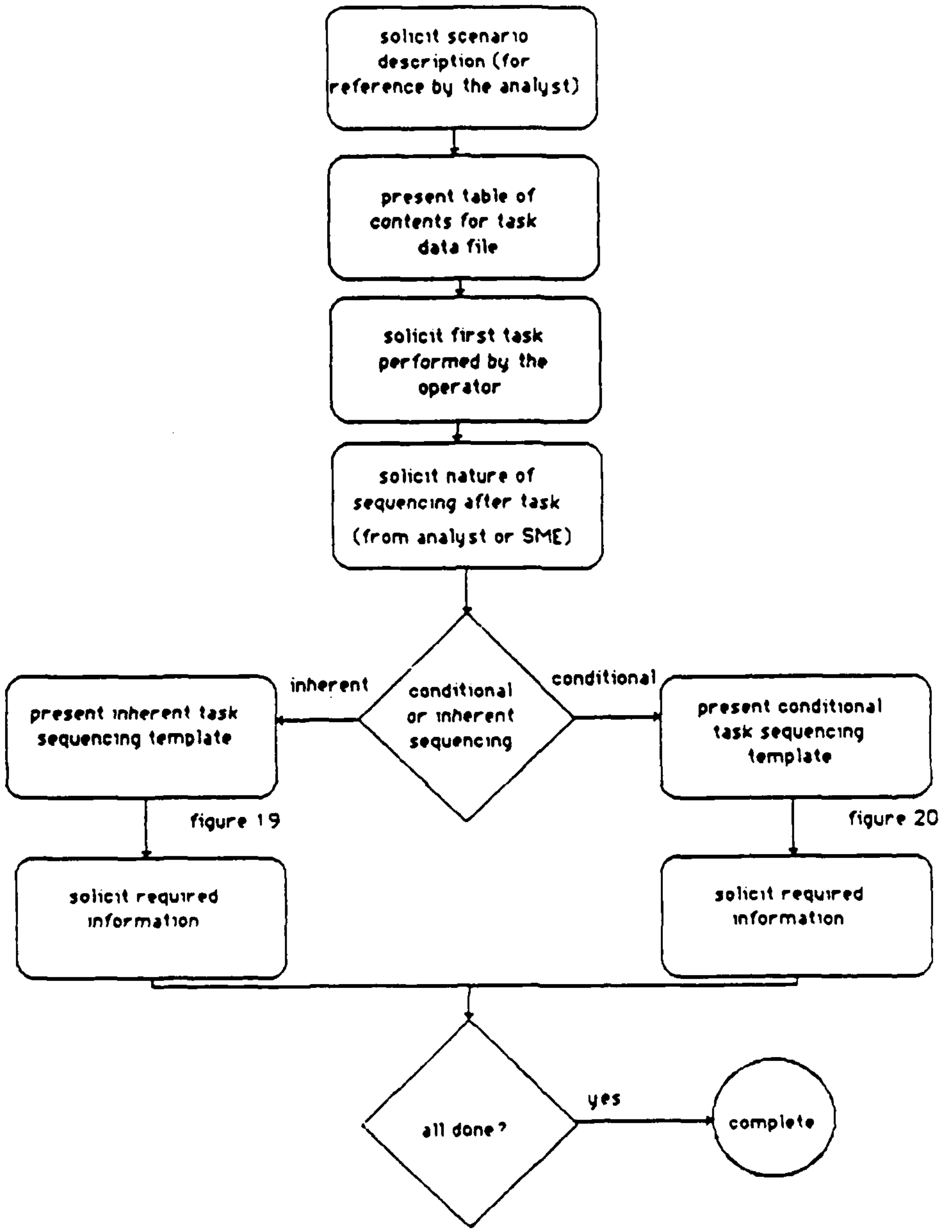

Figure 50. Flowchart for Definition of a New Scenario

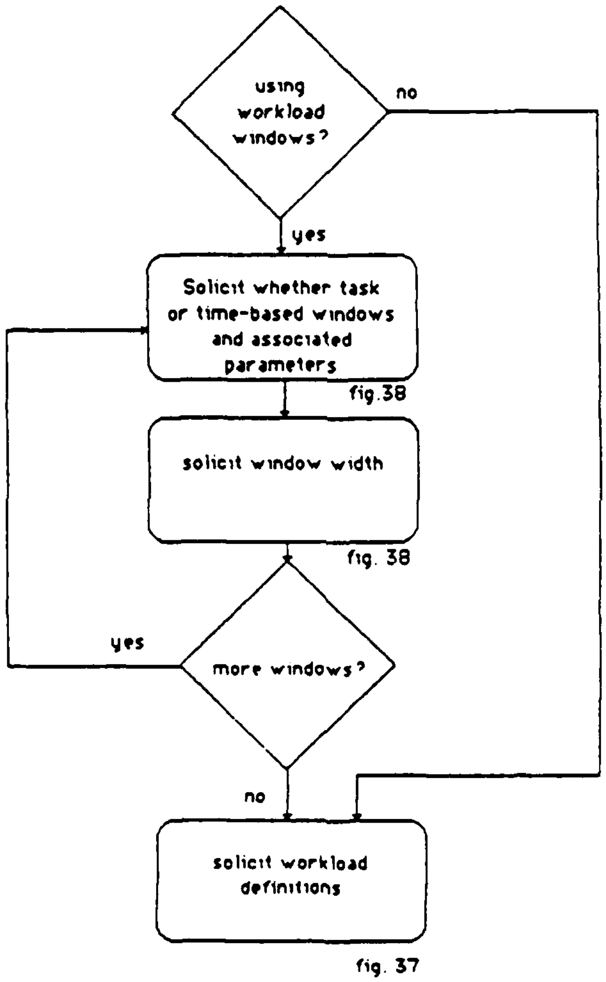

Figure 51. Flowchart for the Development of New Scenarios

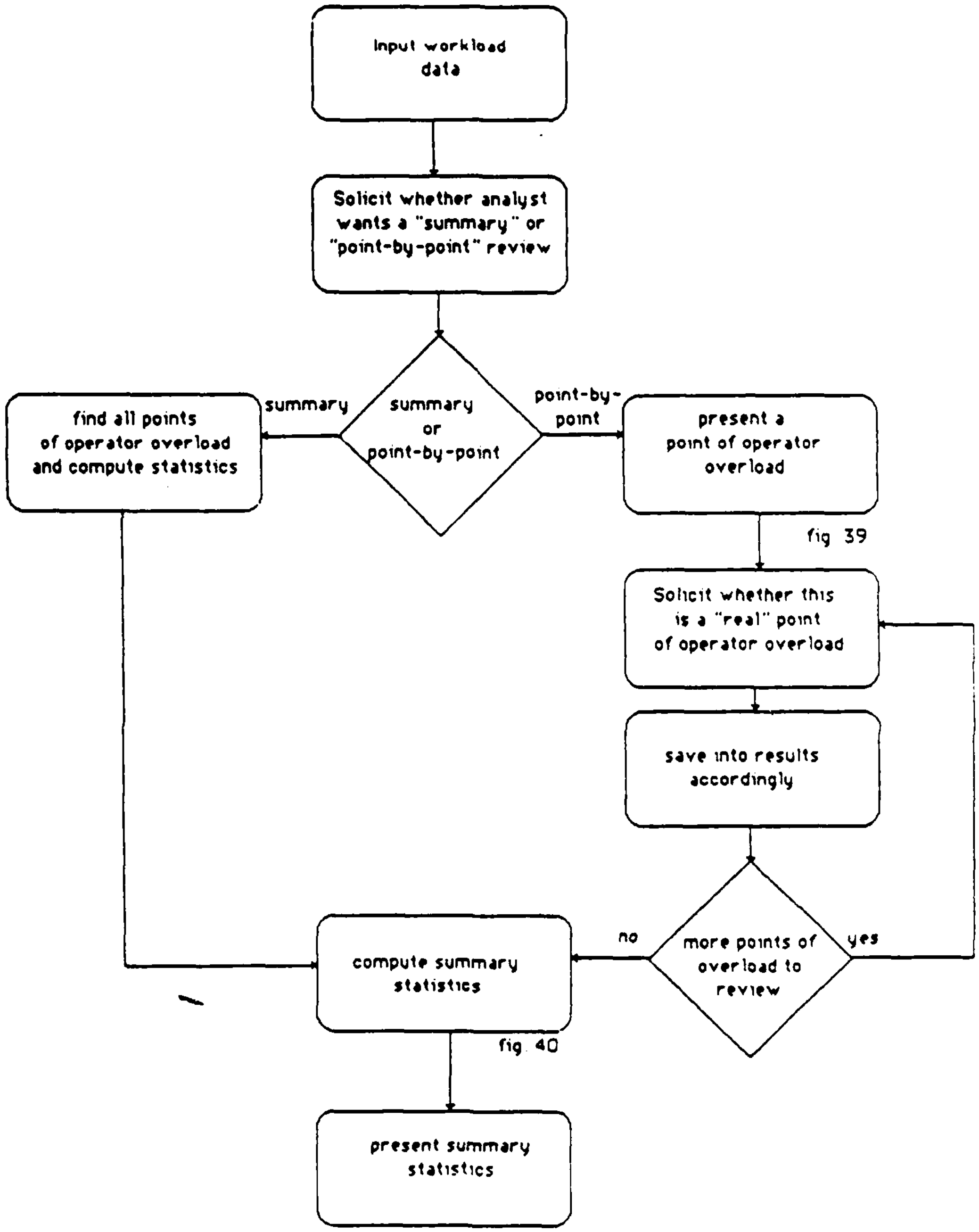

Figure 52. Flowchart for the Review of the Results of the Workload Analysis

issues that should be addressed for each approach, 3) evaluating how much "change" might be reasonable, 4) determining when another operator is essential, and 5) deciding when the system design should be rejected as unable to be operated within the current manpower constraints.

3.3.2 The Libraries

The Libraries are an essential concept behind our approach. We do not believe that it would be reasonable for every MANPRINT analysis to require gathering all new operator task and scenario data. There are many aspects of any new system which are analogous if not identical to existing systems. These existing systems can provide empirically-based data which should be available to the users. It is through the Libraries that these data will be available.

We do not propose that we will be able to develop an all inclusive Task or Scenario Library. There are too many Army systems and potential scenarios to consider such an undertaking. Rather, our strategy will be to develop portions of the Library associated with 1) system types which are likely to require MANPRINT analyses in the near future and 2) develop at least one set of tasks and scenarios for each of the 13 mission areas defined in Kaplan and Crooks (1980). However, embedded in the Task and Scenario Development Templates (as discussed in Section 3.3.1), will be the opportunity to create new operator tasks and scenarios reflecting fielded systems that were not previously in the Libraries. As the analyst collects the necessary data and these files become validated, they can be added to the appropriate Library.

Let us now discuss each of these Libraries individually.

Task Library

This file will include historical data on operator tasks sorted by mission area and function. The information that will be included on tasks will be the following:

1. Task name
2. Task description
3. Associated mission area (e.g., Armor)
4. Specific system type (e.g., M-60)
5. Average task performance time under normal conditions
6. Standard deviation of task performance time

7. Workload requirements in the four workload channels (visual, auditory, cognitive, and psychomotor)

8. Probability of making an error in performing the task (under normal conditions)

The above data will be gathered from the sources discussed in Section 3.2.

None of these data sources will provide workload data. This information will be added to the library by the review of the files which we create by a subject matter expert from the Army working with a psychologist from the contractor team. Experience has shown that these two individuals working together can quickly assign valid workload values to a large number of tasks which will then serve as guidance to analysts using the system.

Scenario Library

This file will include historical data on mission scenarios sorted by mission area. Scenarios represent the sequences of operator tasks and conditions related to specific mission types.

The information that will be stored in these files is the following:

1. A scenario summary

2. A description of the tactical environment

3. A description of the environmental conditions relevant to performance of the scenario

4. Inherent task sequencing relationships as defined by a task network describing task interrelationships

5. Conditional task sequencing describing any tasks in the scenario whose performance is conditional on other tasks or the current battlefield conditions

The sources for the above data are the same as those data sources for the Task Library as described in Section 3.2.

3.3.3 The Files

The Files are created by the analyst during the study of a particular system. Therefore, they will be, in essence, created by the Templates with extensive utilization of the Libraries as starting points.

Task Data File

This file will include all data which the analyst creates defining system operator(s) tasks within each function. The information stored in this file will be identical to the information stored on each task in the Task Library.

Scenario Data File

This file will include all data which the analyst created regarding specific scenarios under which system operation will be studied. The information stored in this file will be identical to the information stored on each scenario in the Scenario Library.

3.3.4 The Models

The Models are the software which will conduct the computer simulation to study operator workload and provide the analyst with tools for data analysis.

The Computer Simulation Model

This program will combine the task and scenario data files and run a computer simulation. Output of this simulation will include workload levels for each operator at predefined time intervals throughout the simulation (e.g., twice a second). These data will be used by the workload data analysis model.

The Workload Data Analysis Model

This program will allow the analyst to review workload data generated by the computer simulation. It will permit him to review points in the mission where workload was excessive based upon whatever definition of "excessive" he chooses to use. It will also generate all outputs defined in Section 3.1.1.

3.4 Estimated Analysis Time

Based on an operator manning analysis defined within this section, we anticipate that a range of 40 - 100 hours of analyst time will be required for a typical major system acquisition.

SECTION 4 - MAINTENANCE MANHOUR ANALYSIS AID (MMAA)

4.1 Overview

This module of the MDA provides the analyst with an aid for estimating the maintenance requirements of a proposed system design in terms of the number of jobs required to maintain the system, the number of people required per job, and the maintenance tasks that are included in each job. The ultimate goal of this analysis is for the Army to determine whether the numbers and types of soldiers required to maintain the proposed system are in line with the personnel that will be available if the design is funded.

4.1.1 Differences Between Operator and Maintenance Workload

The approach for determining maintenance requirements using the MMAA differs from the approach for determining operator manpower requirements using the WAA. The reason for the difference is primarily in the way we define workload for operators versus maintainers.

Operators of a military system are often required to perform a number of different tasks simultaneously, or in a parallel fashion. For example, a tank commander must listen for radio communication at the same time he is visually monitoring both the battlefield for threats and instruments inside the tank. While all of this is happening, the tank commander is also cognitively processing all of the information he is receiving through the other sensory channels. The number of simultaneous tasks that can be performed by an individual operator has an upper limit beyond which the operator must begin dumping some tasks to be able to perform others or decreasing the accuracy with which each of the tasks is performed. Either of these strategies for coping with work overload is potentially detrimental to system effectiveness and the survivability of the operator or crew. The distribution of tasks (jobs) for operators of any proposed system should be designed so that the number of people required to operate the system is at a minimum while at the same time no individual operator is assigned more tasks than he can perform effectively. Therefore, our approach for determining the manpower requirements for operators of the system is to simulate the sensory channel workload requirements for each operator of the system. When the simulation indicates that the proposed allocation of tasks to jobs results in excessively high workload for an operator, it means that the average operator probably can't do the job. Therefore, job and task reallocation is necessary or more operators are necessary to reduce the workload to acceptable levels.

Maintenance personnel don't perform maintenance tasks simultaneously. They work in more of a serial fashion. Workload for maintenance activities is defined in terms of the number of maintenance tasks that must be performed in the allotted time between missions and how many people it takes to perform all of the required tasks. When a maintenance person finishes one task the next task is started. Therefore, maintainers are not really affected by sensory overload as are operators. They are however, affected by the number of maintenance tasks that are in the queue. For example, an attack helicopter may require maintenance on three different electrical system components before it can be used on the next scheduled mission. All three tasks are within the scope of one maintenance job. However, if the time it takes to perform all three tasks is longer than the amount of time before the next scheduled mission, the system will not be available to perform the mission unless more than one person is assigned to that maintenance job.

Another important distinction between operators and maintainers of a system is the way that "jobs" are defined. It's easy to see that assigning jobs in terms of groups of tasks to members of a crew that will operate a system can be done at some initial stage of system design without regard to MOS, skill, or pay grade. This works because operators of an Army system are dedicated to that system. For example, soldiers with the same MOS can be assigned different jobs as members of a gun crew. Each is assigned a number of tasks that represent part of the operation of the system. The critical questions to be answered with regard to manpower requirements for the operation of a system are (1) What tasks should be assigned to what jobs so that no operator has more than he can effectively do? and (2) How many of each job are necessary to ensure optimal workload?

Maintenance personnel, on the other hand, are not dedicated to a single system. In most cases, a maintenance person is assigned to work on more than one type of system (e.g. helicopter hydraulics maintenance rather than UH-60 hydraulics maintenance). As a result, the Army doesn't normally assign jobs or duty positions to maintenance personnel as it does with operators. Therefore, maintenance jobs will be defined for the MMAA as the combination of a specific MOS and skill level and maintenance category. The analyst will be able to define, for his own analysis, a subset of this definition. For example, the analyst may want to consider only MOS and skill level without regard to maintenance category as a maintenance "job".

Maintenance and operator workload also differ in the time units necessary to conduct a workload analysis. Operator workload must be assessed over the time period of a typical mission. Maintenance requirements must be assessed over a much

longer period (usually one year). This, combined with the fact that a system is maintained by personnel that are also working on other systems, is the reason that maintenance requirements are typically measured in the Army in terms of annual maintenance manhours per maintenance job.

While annual maintenance manhours is an appropriate way to assess maintenance manpower requirements, it can be misleading without some additional information. Annual maintenance manhours per maintenance job, divided by the number of hours available for a single maintainer per year does not reflect times when the number of maintenance personnel needed for a particular job is greater than the hours would indicate. This is because the ability to maintain the system in the time allotted between missions has a direct result on system availability. Therefore, to meet the system availability requirements, it may be necessary to assign more than one person to perform the tasks for one maintenance job, even though the annual maintenance manhours are less than one full-time person.

To avoid this misinterpretation of annual maintenance manhours per job, the MMAA will also keep track of the actual number of people required to maintain the system and the percentage of time during the maintenance period that number were required. For example, if a particular system has an annual maintenance manhour requirement that is less than one full time maintenance job, based on annual maintenance manhours, it is also important for the analyst to know that 40 % of the maintenance time over the period being analyzed, it required two people assigned to that maintenance job to ensure system availability.

4.1.2 Theory Behind the MMAA

The fundamental assumption for the MMAA is that every new or modified system design under evaluation is comprised of individual hardware and software components that need to be maintained to either prevent or correct a malfunction or failure of that component. The rate that the components fail or need preventive maintenance is different for every component and is almost always directly related to the amount of use that component has received (realizing that there are components that require maintenance purely as a function of time e.g., "lubricate joint").

Furthermore, since each system is a part of a military mission, there is only a limited amount of time available for maintenance of system components without taking away excessively from the system's availability to perform missions. Therefore, if we can estimate parameters that describe the maintenance requirements for each component and parameters that describe the usage rate for each component, we can feed that information into a generic maintenance manning simulation model to calculate the

maintenance manpower requirements for the overall system. In general terms, component maintenance parameters include:

- The rate at which each component requires maintenance.
- The maintenance action(s) required.
- The time it takes to perform the maintenance.
- The type of person required to perform the maintenance (i.e., MOS, Skill level and Category).

A more detailed discussion of the specific component maintenance parameters is included in Section 4.2.1 on page 150.

Again in general terms, the component usage parameters include:

- The usage rate for each component per mission.
- The average length of a mission.
- The frequency of missions.

A more detailed discussion of the specific component usage parameters is included in Section 4.2.5 on page 175.

4.1.3 Overview of the MMAA Approach

The backbone of the MMAA will be a maintenance manning network simulation model similar in function to that of the Logistics Composite Model (LCOM) developed for the Air Force. However, this model differs from LCOM in that it is embedded within the MMAA and does not require the analyst to develop any of the complex modeling logic required by LCOM. Another advantage of the simulation model developed for the MMAA is that, rather than treating maintenance as a portion of the overall logistics support analysis, it is designed specifically for evaluating a particular system design in terms of the maintenance jobs that are required, the number of personnel required for each maintenance job, and the specific maintenance actions or tasks that comprise each maintenance job.

While the backbone of the MMAA is the simulation model, the major focus of the aid is to:

- provide Army analysts with access to data that will assist them in estimating the component maintenance requirements of the system design under evaluation.

- provide analysts with guidance in estimating and entering component maintenance parameters and system usage rates needed as input to the simulation model for each potential mission scenario required of the proposed new or modified design.

- To provide the analyst with mechanisms for retrieving, organizing, and interpreting outputs of the simulation with respect to the maintenance jobs that are required, the tasks are assigned to each job, and the number of people that are needed for each maintenance job.

The approach used by the MMAA for determining maintenance jobs, number of maintainers per job, and maintenance tasks per job is to model the overall maintenance requirements for the system based on the expected failure rates or planned maintenance schedules of each system hardware and software component, mission scenario system usage rates, and the time it takes to perform each maintenance task.

The process of determining maintenance requirements for a new or modified system design consists of four general activities. The first is to identify the most accurate estimate possible of the maintenance parameters for each hardware or software component in the contractor's design. Table 4 contains a list of the Component Maintenance Parameters that will be used by the MMAA simulation model to calculate how often each component needs maintenance, the maintenance task required, and who should perform the maintenance.

The next activity for the analyst is to identify parameters for each potential mission scenario required of the proposed or modified system. This data will be used to determine the usage rates for each of the system components and to determine the "window" of time available for maintenance between missions. Table 5 contains a list of the Mission Scenario Parameters. These parameters will be used by the MMAA to model component breakdown or malfunction and planned maintenance.

The third general activity is for the analyst to exercise the computer simulation model that is embedded in the (MMAA) to calculate the maintenance manpower requirements for the overall system.

The last activity is to analyze and evaluate the results of the simulation model and to investigate potential solutions to maintenance deficiencies.

Table 4 Component Maintenance Parameters

- The name of the component
- The maintenance action to be performed
- The MOS and skill level needed to perform the maintenance
- Maintenance type (e.g. planned, corrective)
- Mean operational units between failure of the component (e.g., time, rounds fired, flight hours, etc.)
- The maintenance category (e.g., org, ds, gs, depot)
- Mean times and standard deviations for maintenance actions
- Maintenance accuracy (for diagnose or troubleshoot activities)
- An indication of whether or not the failure of each component could result in a mission being aborted
- The operational conditions (e.g., terrain, weather, threats, etc.) that are represented by the data in the component library

Table 5 - Mission Scenario Parameters

- Simulation Period
- Number of Missions per Day
- Mission Length
- Mission Frequency
- Operational Units per Mission for each Component

4.1.4 Steps the Analyst Will Follow in Using the MMAA

In applying the MMAA, the four general activities described above are further broken down into eight steps that the analyst will perform. Section 4-2 contains a detailed discussion of each of the eight steps involved in using the MMAA. Following is a brief description of each step (page number references for the detailed explanation in Section 4-2 are included):

1. Enter the system components and all available maintenance parameters from the contractor's design. (see page E1-150)

2. Match system components and parameters from the contractor's design to baseline estimates from comparable systems. (see page E1-157)

3. Identify discrepancies between the government baseline estimates and the contractor's design estimates of component maintenance parameters. (see page E1-169)

4. Resolve the discrepancies to determine the "best estimates" of component maintenance parameters. (see page E1-172)

5. Identify and develop parameters for each mission scenario to be analyzed in terms of maintenance manhour requirements. (see page E1-175)

6. Exercise the computer simulation to calculate the maintenance manhour requirements, system availability, and system reliability for each mission scenario. (see page E1-180)

7. Evaluate the results of the computer simulation in terms of the maintenance jobs that are required, the tasks that make up each job, the number of maintenance hours required per job, system performance requirements and manpower constraints. (see page E1-182)

8. Investigate potential solutions to maintenance deficiencies by modifying component maintenance parameters and re-running the model to determine the effect on system reliability, availability, and maintenance manpower requirements. (see page E1-184)

Figure 53 is an illustration of the sequential flow of the eight steps that the analyst will follow.

4.1.5 Outputs

Each time the analyst executes the Maintenance Requirements Simulation Model that is embedded within the MMAA, the model will calculate a variety of data that will be stored in a simulation results file for that particular mission scenario. This results file will serve as a relational data base of maintenance requirements. Using the Reports Generator, described in Section 4.3 page 185, the analyst will be able to display or obtain a hard copy of a simulation results summary report. The summary report will consist of a table of information that contains the following information for each maintenance job (MOS, Skill level and Category) that was entered as a Component Maintenance Parameter:

- All of the maintenance actions (tasks) that were assigned to the maintenance job.
- The number of times each task was performed.
- The total number of maintenance hours for each task.
- The total number of maintenance hours for each maintenance job.

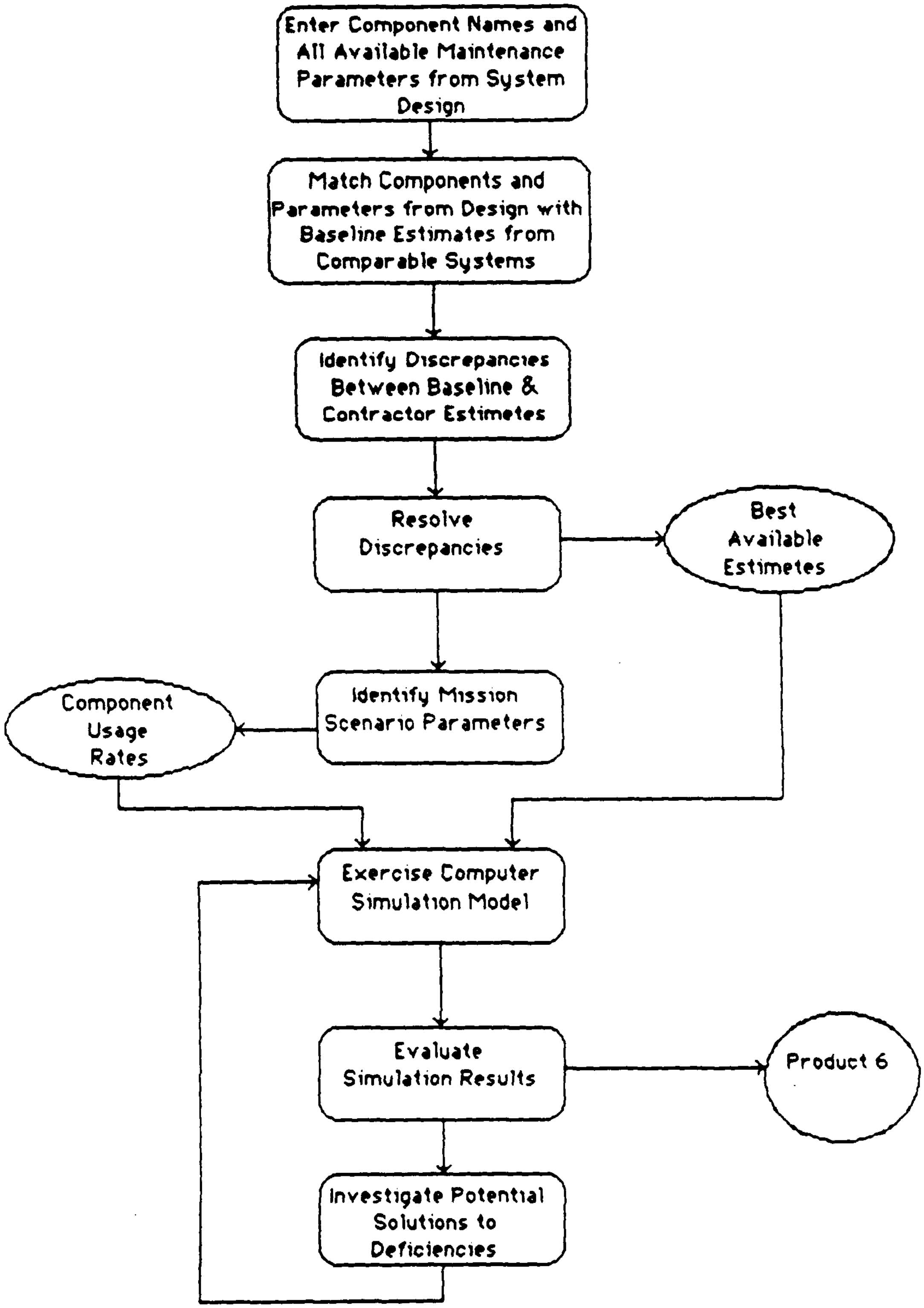

Figure 53. Steps in Using the Maintenance Manhour Analysis Aid

In addition to the report of maintenance manhours for each maintenance job, the MMAA Reports Generator will also produce a histogram of the actual number of maintainers needed for each maintenance job and the percentage of the total maintenance time each number was needed. For example, the total number of annual maintenance manhours for a particular maintenance job may be only 1355, which is less than one full time maintainer. However, due to the maintenance windows that are imposed because of the system's need to perform missions, the histogram may show that, for 70 % of the maintenance time during that period, 2 people were required. Figure 54 is an illustration of a histogram of maintenance headcount requirements.

The analyst will also be able to use the Reports Generator to extract and report any other combinations of data contained in the simulation results data base. Following is a list of some of the other results contained in the data base:

- The number of times a mission was missed due to maintenance.
- The percentage of time the system was available when needed for a mission.
- The percentage of time a mission had to be aborted for maintenance.

For more detailed information on the outputs of the MMAA, refer to Section 4.2.7 on page E1-182, and Section 4.3.2 page E1-188.

4.1.6 Automated Components for the MMAA

The software elements that comprise the Maintenance Manhour Analysis Aid (MMAA) are grouped into the following categories:

1. Templates - consist of sets of menus, prompts, and spreadsheet-like interfaces for users to create and gain access to data files and military data bases.
2. The Component Maintenance Parameter Library - includes historical data on maintenance parameters of fielded military weapon systems.
3. Direct Access to Military Maintenance Data Bases - Although not formally an MMAA software component, we will develop communication software that will allow the analyst to access selected maintenance historical data bases of fielded systems, such as the Sample Data Collection Data Base, to assist the analyst in determining Component Maintenance Parameters.

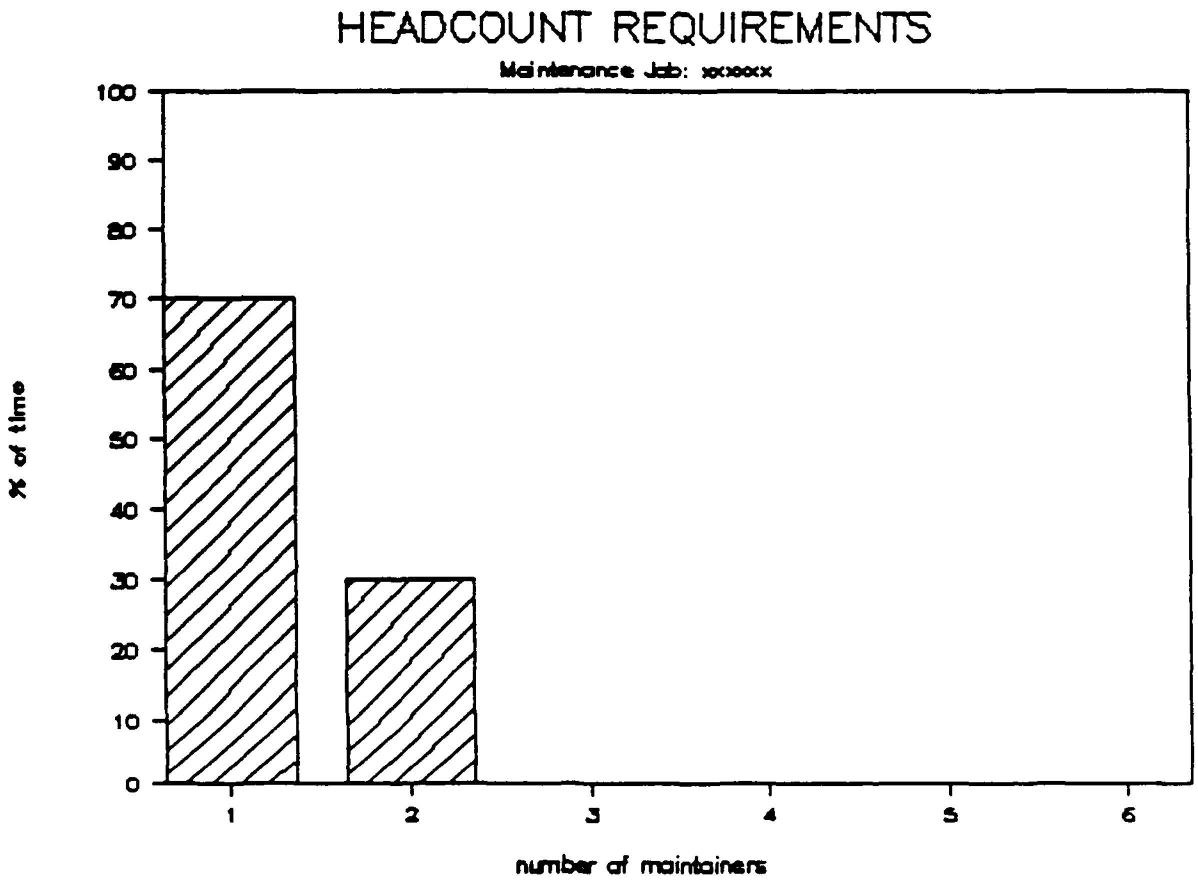

Figure 54. Histogram of Maintenance Headcount Requirements

4. <u>Data files</u> - store information specific to the evaluation of a proposed system design. Data files store both input and output data that is used and produced by the other software components.

5. <u>The Maintenance Requirements Simulation Model</u> - is the generic maintenance network simulation model used to calculate estimated maintenance manpower requirements.

Like the WAA, the MMAA will have an Application Manager that is the underlying software operating system that controls the transfer of information between all of the software components.

The nature of the these five software elements is essentially the same as those discussed for the WAA in Section 3.1.3.

4.1.7 Overview of Approach for Product Development

The approach to product development will mirror the approach for the WAA. This is discussed in detail in Section 3.1.4, but let us repeat the highlights of the approach below.

Virtually all of this aid will be automated with the exception of some basic documentation to "get the analyst started." Therefore, let us discuss product development in the context of the development of the five categories of software described above.

The four sets of software which will need to be developed as part of product development are the Templates, the Component Maintenance Parameter Library, the software to provide direct access to maintenance data bases, and the Maintenance Requirements Simulation Model. The fifth set of software, the Files, will be created by analysts as they use the MMAA. Let us briefly discuss the development of the Templates, Component Maintenance Parameter Library, direct access to military maintenance data bases, and Maintenance Requirements Simulation Model individually. More detail on each of these is presented in Section 4-3.

<u>The Templates</u> - As we stated earlier, the underlying software which will support the use of computer simulation is Micro SAINT. We will use the power of Micro SAINT model execution and data generation but will develop specific model development software aimed directly at maintenance manning analysis. Therefore, rather than a general model development interface as currently exists, we will have a very "MMAA specific" interface.

In this task, we have identified preliminary user steps and user interfaces. We emphasize that the user interfaces are preliminary, intended more to illustrate ideas and clarify points than to provide specific interfaces. In Task 2 of this effort, we will develop specific user scripts which will be submitted to users for comments. Additionally, we will develop data flow diagrams linking user interfaces to the generation of the Files which will be used in the analysis.

The Component Maintenance Parameter Library - Our basic philosophy for developing the library will be to construct a set of entries for Component Maintenance Parameters for fielded systems into the library during Task 3 of this effort. This set will be selected so that it represents the mission areas which are likely to require MANPRINT analyses in the near future based on existing requirements. Additionally, we will embed mechanisms into the software for adding task and scenario files to the libraries as users conduct MANPRINT analyses on new systems. In doing this, analysts will be able to create their own files representing a new system and then, if appropriate, add that file to the library. In essence, we propose to develop enough pieces of the library to bootstrap the use of this tool. Then, as the aid is used, the libraries will grow reflecting new system designs.

In Task 2 of this effort (development of detailed design specifications), we will develop data base formats (e.g., field definitions, record lengths) as well as software for the creation and management of these libraries. Additionally, we will finally define all data sources for the specific entries into the libraries to be developed in Task 3 of this effort.

Finally, in Task 3, we will develop the library management software and construct the subsets of the libraries defined in Task 2.

Direct Access to Military Maintenance Data Bases - To supplement the Component Maintenance Parameter Library, we will develop the software to allow the analyst to access military maintenance data bases, such as the Sample Data Collection Data Base, that reside outside of the MMAA. DRC currently maintains a direct link to the SDC Data Base. Although these data bases will not be considered a formal part of the MMAA, the communication and data conversion software we develop will use the concept of "software windows" to access the data base without leaving the MMAA. The software that we develop to give the analyst access to maintenance data bases will also include user interfaces that are consistent with the other components of the MMAA. The analyst will be able to query the data bases from a menu and prompt driven interface that is a part of the MMAA rather than being forced to use the data base query languages

that are required by the data bases themselves. The analysts will use these data to help identify Component Maintenance Parameters for comparable systems that don't reside in the Component Maintenance Parameter Library.

In Task 2 of this effort, we will identify the data bases for which direct access will be provided and develop detailed software specifications. Finally, in Task 3 we will complete all software development, debugging, and operational testing of the software.

The Maintenance Requirements Simulation Model - As was stated in the discussion of Templates, the basis for all models will be Micro SAINT. Again, however, the analyst will not "see" Micro SAINT, he will not "execute" Micro SAINT models, nor will he "analyze" Micro SAINT data in the ways that a user of Micro SAINT would. Rather, by creating Component Maintenance Parameter files and Mission Scenario files, the analyst will have created all of the information necessary for the simulation. Our modeling software will create Micro SAINT models directly from these files, execute them, collect the appropriate data, and then analyze the data, all in the specific context of maintenance manning analysis.

In Task 2 of this effort, we will develop detailed software specifications and, in fact, we expect to be able to begin some coding within the available time. Finally, in Task 3 we will complete all software development, debugging, and operational testing of the models.

4.2 Detailed Discussion of the Steps Followed by the Analyst Using the Maintenance Manhour Analysis Aid (MMAA)

The purpose of this module of the Manpower Determination Aid (MDA) is to assist the analyst in evaluating initial contractor designs during the proof of principal phase of the acquisition process by estimating the maintenance workload required to maintain the system. Workload is specified in terms of the maintenance jobs that are required (MOS, skill level and Category), the number of jobs, and the maintenance actions or tasks per maintenance job. The overall outputs obtained from the use of this aid will be evaluated in terms of the manpower constraints for maintenance workload (i.e., AMMH) that are determined during the system requirements specification phase of the acquisition process.

The MMAA guides the analyst through the process of defining component maintenance parameters and system usage rates for each potential mission scenario required of the proposed or modified system through the use of menus, prompts, templates, a Component

Maintenance Parameter Library, and military maintenance historical data bases. The analyst can then exercise the computer model to calculate the maintenance requirements for the overall system.

The analyst will compare the results of the simulation with the output of the System Performance Requirements Estimation Aid (SPREA) developed in product 1 and the Manpower Constraints Estimation Aid (MCEA) developed in product 2 to evaluate the system design for maintenance deficiencies.

The MMAA can also be used as a tool to simulate potential solutions to maintenance deficiencies such as the effects of increased component reliability or decreases in mean repair times on overall system maintenance workload.

The next sections of this concept paper will discuss in detail each of the eight steps the analyst will follow to use the MMAA (listed in section 4.1.2). For each step, we will include the required input data, data sources, the process for performing the step, the software interfaces associated with the automated portions of the process, and the output of the step.

4.2.1 Step 1 Enter the system components and all available maintenance parameters from the contractors design.

Input

Internal - The input for this step that is included within the MMAA are the Component Maintenance Parameter templates. The development procedures and data sources for the templates are discussed in detail in section 4.3 of this concept paper.

External - As a part of the contractor's Logistic Support Analysis Record, they should conduct a task analysis to indicate the quantitative, qualitative, and procedural requirements for all planned and corrective maintenance activities for each system component. The results of the LSA will be documented in the LSAR. The contractor's design will indicate all of the system components and sub-components. A schedule of planned maintenance activities should indicate the operational units between each planned maintenance action such as the number of miles traveled, time, or rounds fired. As a part of the LSA, the contractor should supply reliability information indicating the mean operational units between failure for each component and information on the frequency distribution of the failures. The contractor's design may also indicate whether or not the failure of a particular component would cause a mission to be aborted.

In addition to the LSAR, other maintenance task information may be available in separate task analyses conducted for training or for human factors analyses. The latter would be documented in the Human Engineering Design Analysis Document for Maintenance (HEDAD-M).

The maintenance task analysis should indicate maintenance actions for both planned and corrective maintenance for each system component.

Following is a sample list of typical maintenance actions (Kaplan and Crooks 1980):

inspect
lubricate
fill
drain
purge
paint
clean
remove or change or replace
troubleshoot or diagnose
repair
disassemble or assemble
install
adjust or align
test

For each maintenance action, the task analysis may include the following information:

- mean and standard deviation of time to repair
- maintenance category
    - crew
    - organizational
    - direct support
    - general support
    - depot
- the number of each MOS and skill level required
- tools and equipment needed
- special requirements for maintainers (e.g. height, security clearance)

<u>NOTE:</u> This description of input data to be obtained from the contractor's design documentation and maintenance task

analysis represents a "best case" situation. In reality, the contractor may supply only a portion of this information. At the very least, however, the design should include a list of the individual system components. The process for using the MMAA takes into consideration design documentation that contains only a minimal amount of maintenance task information.

Process

The first four steps in the process of utilizing the MMAA are all aimed at obtaining the best available estimates of the maintenance parameters needed as input for the Maintenance Requirements Simulation Model for each hardware or software component in the system design. Table 4 on page 141 lists each of the Component Maintenance Parameters. Step 1 of this four step process is for the analyst to enter all of the components from the system design and as many of the maintenance parameters for each component as are available in the design documentation into a Component Maintenance Parameter Template. The analyst begins this step by accessing the MAINTENANCE MANPOWER ANALYSIS AID main menu. Figure 55 is an example of what that menu might look like.

From the MMAA main menu, the analyst can enter the name of the major system whose design is being evaluated. When the analyst selects the "Component Maintenance Parameters" option from the main menu, a screen similar to the one shown in Figure 56 will display a list of all of the functional systems within the major system being evaluated that have been entered so far. A functional system is defined as a group or set of components that perform a function within the overall system (e.g., avionics system, cooling system, engine, etc.). System components and their associated maintenance parameters are entered into Component Maintenance Parameter Templates by functional system.

From the functional system listing, the analyst can enter simple one-letter commands to add, modify, delete, copy, or save functional systems.

When the analyst chooses to add a functional system, a prompt will be displayed asking the analyst to enter a name for the new functional system. When the analyst enters a name, a Component Maintenance Parameter Template, similar to the one shown in Figure 57 will be displayed.

```
                Maintenance Manhour Analysis Aid Main Menu

        1.    System Name In Memory:  M60 Tank

        2.    Develop Component Maintenance Parameters

        3.    Develop Mission Scenario

        4.    Execute Maintenance Simulation

        5.    Analyze Simulation Results

        6.    List Current Systems

Enter a number and then press <RETURN>_
```

Figure 55. Maintenance Manhour Analysis Aid Main Menu

Working File Listing of Functional Systems

```
                    Functional Systems

   Major System:  M60 Tank

        1.   Armament System
        2.   Engine
        3.   Communications
        4.
        5.
        .
        .
        .
        .


Command (a, m, d, c, s):_

add = add functional system components using a blank template
modify = display existing functional system template
delete = delete a template
copy = copy a template from the Library or another working file
save = save all changes made to this working file
```

Figure 56. Listing of Functional Systems

Major System: M60 Tank

Functional System: Engine

Component Name	Maintenance Action	Mean Units Between Failure	Mean Time to Repair (TTR)	Standard Deviation TTR	Maint. Org.
Fuel Injection	adjust	107.5	.5	.2	GS
Cylinder Head	repair	1020	11.4	3	DS
Crankshaft	repair	920	9	1.5	DS
Seals, main	replace	870	2.5	.4	DS

Baseline Estimates

Contractor Estimates

Figure 57. Component Maintenance Parameters Template

The Component Maintenance Parameter Template is a matrix of rows and columns of cells with an interface much like that of an electronic spreadsheet. In the left-most column of the template, the analyst will enter the names of the functional system components directly from the contractor's design. The rows of cells to the right of the component names, will contain the maintenance parameter entries for each component. The top row contains the column headings representing each of the component maintenance parameter.

Each cell of the spreadsheet is divided into two sections. The top portion of the cell will eventually contain the Army's estimate for each Component Maintenance Parameter. The bottom portion of each cell is reserved for the contractor's estimate, if it is available. As the analyst enters the component name from the design, he or she will also enter any of the maintenance parameters that are included in the design. While it is unlikely that the contractor will include all of the maintenance parameters in the design, it is likely that some will be available. The contractor's estimates of maintenance parameters will be compared to Army estimates later in the analysis process. The reason for this is that, even in the design of a new weapon system, probably not every component in every functional system is an entirely new design. Therefore, the maintenance parameters for some of the components may be clearly understood by both the Army and the contractor. In cases where both the Army and the contractor agree on a component maintenance parameter, it is probably safe to assume that it is the best available estimate.

The analyst will continue this process of entering components and the available parameters from the system design until the components for all of the functional systems have been entered.

Output

The output of this step is a set of matrices containing the names of the hardware or software components in each functional system of the design being evaluated and the contractor's estimates of component maintenance parameters. These matrices will be stored in the Component Maintenance Parameter File. There may be some data missing from the contractor estimates due to missing information in the system design documents.

User Interface Issues

The user interfaces for entering the component names and maintenance parameters by functional system from the system design will consist primarily of menus, prompts, simple one letter commands, and spreadsheet-like templates. Context specific help will be available to the analyst at all points

during the process.

The actual design of menus, selection procedures, and keyboard routines will be developed based on input from intended users, human factors analysis, and the final software design.

4.2.2 Step 2 Match baseline estimates to system components and parameters from the contractors design.

Input

Internal The input for this step that is included within the MMAA will be 1) Component Maintenance Parameter Files containing the names of each hardware or software component by functional system created in Step 1, 2) the Component Maintenance Parameter Templates for development of estimates of component maintenance parameters that are based on parameters of comparable fielded systems and 3) the Library of component maintenance parameters for selected fielded systems.

The development procedures and data sources for the templates and the library of component maintenance data for fielded systems are discussed in detail in Section 4.3 of this concept paper.

External

- Army Annual Maintenance Manhours Data Base (AMMDB)
- Sample Data Collection System Data Base
- Army equipment inventories of fielded systems
- System design specifications for fielded systems
- Technical Manuals for maintenance activities
- Subject Matter Experts

Process

The process of identifying baseline estimates of system component maintenance parameters is dependent on the availability of fielded system data within the Library of component maintenance parameters. During the development of the MMAA, we will develop component maintenance parameter data for a selected number of fielded systems in different mission areas. These data will reside in the Library that can be accessed by the analyst. However, it will not be possible to develop baseline data for every type of major weapon system in every mission area. Therefore, in cases where a data from suitable baseline system does not exist in the Library for the system being evaluated, the analyst will need to identify the component maintenance parameters for a similar system from other available sources.

Upon completion of the component maintenance parameter identification process, the analyst will have created a file containing baseline data and possible contractor estimates to use as a starting point for determining the best available estimates of the component maintenance parameters of the proposed new or modified system.

We anticipate that as the use of the MMAA expands, the inventory of maintenance data for major systems in the Component Maintenance Parameter Library will continue to grow. When a system design is ultimately approved and fielded, the baseline estimates of component maintenance parameters that are used for the manhour requirements analysis can be updated with actual usage data and added to the library.

The process of identifying baseline system component maintenance parameters will therefore be discussed in terms of situations when 1) a suitable system in the baseline library does exist and 2) when the analyst must identify new baseline estimates.

Selecting Components from the Baseline Library

From the Component Maintenance Parameter Template, the analyst will be able to create software "windows" for access to the Component Maintenance Parameter Library to search for comparable system components used in fielded systems. Defining the software windows and accessing the library will be accomplished through the use of embedded menus similar to the ones used by commercial spreadsheet packages and word processing software.

Once the analyst has gained access to the library, he or she can search for comparable system components and copy the maintenance parameters into the template by switching back and forth from the library window to the Component Maintenance Parameter Template window.

When the analyst is working in the library window, a series of menus will allow him or her to converge on system components of the fielded systems contained in the library.

The MMAA will first provide the analyst with a menu of Mission Areas into which the system being evaluated will fit. The following is a sample list of Mission Areas taken from a taxonomy developed by Kaplan and Crooks (1980):

- Air Defense Weapons
- Armored Vehicles
- Aviation Systems

- Battlefield Communication Systems
- C^2 and C^2I Systems
- Combat and Technical Support Equipment
- Electronic Warfare and Surveillance Systems
- Ground Transportation Systems
- Infantry Weapons
- Ordinance Systems
- Target Acquisition and Designator Systems

When the analyst selects a Mission Area, he or she will be presented with a list of major system categories that fall under that Mission Area. For example, if an analyst selects "Armored Vehicles" as the Mission Area, a menu similar to the one shown in Figure 58 will be displayed. From this screen, the analyst can select a category for the system under evaluation.

When the analyst has selected a category, he or she will have access to component maintenance parameter data for one or more fielded systems within that category that reside in the Library. These data can be used as a baseline or starting point for the government estimates of maintenance requirements. In the example used above, if the analyst selects "main battle tanks" as the major system category, a menu of fielded main battle tanks for which component maintenance parameters are contained in the Library will display on the screen. Figure 59 is an example of what the menu might look like. This example, and all examples of user interfaces are intended to convey the context of the information presented to the analyst. The final formats and designs of all user interfaces will be based on the final software design, human factors analysis, and input from potential users of this aid.

The components for each major system in each library are grouped according to the functional systems within the overall system (e.g., hydraulic, avionics, armament, etc.) When the analyst selects a major system, a menu of the functional systems within that major system will display on the screen. Figure 60 illustrates a sample menu of functional systems.

The process of selecting a specific major or functional system from the Library of Component Maintenance Parameters will involve the analyst selecting from a series of menus described above. These menus will allow him to converge on specific subsets of component parameters of interest to him.

Select Major System Category Menu

Select Major System Category

Mission Area: Armored Vehicles

1. Main Battle Tanks
2. Armored Reconnaissance Vehicles and Light Tanks
3. Infantry and Calvary Fighting Vehicles
4. Armored Personnel Carriers

.
.
.
.

Enter a number and then press <RETURN>:_

Figure 58. Major System Category Menu

Select Major System Menu

Select Major System

Mission Area: Armored Vehicles
Category: Main Battle Tanks

1. M60
2. M1
3.
4.

Enter a number and then press <RETURN>_

Figure 59. Major System Menu

Select Functional System Menu

```
                    Select Functional System

Mission Area:  Armored Vehicles
Major System:  M60 Tank

     1.   Hydraulic system
     2.   Armament
     3.
     4.
     5.   Engine
     .
     .
     .

Enter a number and then press <RETURN>_

quit = go to previous screen  <esc> = return to working file
```

Figure 60. Functional System Menu

There are good reasons to organize the components by functional system. The first is that it allows the analyst to work with a manageable portion of an overall system. It also may be that the design being evaluated is only a modification of an existing system. In this case, there may be a number of functional systems that will not be modified.

Another major benefit to accessing component maintenance parameter data from the library by functional system rather than by overall system is that it makes it possible for the analyst to build a data file of maintenance parameters for the design being evaluated from functional systems of more than one major system. For example, a proposed new helicopter may include an avionics system similar to that of an Apache and a hydraulic system more like that of a Cobra.

Working with component data by functional system also encourages a top down approach to the estimation of component maintenance parameters.

When the analyst has selected a subset of components within the overall major system, he or she will be able to scroll through a list of components within that functional system, similar to the illustration in Figure 61. For each component in the list, there will be a description that will include:

- the function of the component.
- its approximate location in the system.
- other identifying information such as an indication of size or a MIL SPEC number .

The component description will help the analyst determine if the component is comparable to the one in the system design. When the analyst locates a component that is appropriate to use as a baseline estimate, he or she can display the maintenance parameters for that component and copy them directly into the Component Maintenance Parameter Template.

Table 4 contains a list of the component maintenance parameters included for each major system component in the baseline library. These parameters are required as input for the simulation model.

When the analyst decides to exit from the list of components in the current functional system, he or she is presented with a display of the functional systems currently saved in the working file similar to the one shown in Figure 62. From this screen, he or she will be able to copy the component maintenance parameters of another functional system from the Library. The analyst continues this process of copying component maintenance parameters from the functional systems of similar major systems in the Library until all of the functional systems included in the design that is being evaluated have been covered.

<u>Identifying Baseline Estimates from Other Available Sources</u>
When there is no major system or functional system in the baseline library that is suitable for use as baseline estimates of component maintenance parameters for the design that is being evaluated, the analyst will have the option to obtain similar system component data from other available sources and enter it into blank Component Maintenance Parameter Templates. When the analyst exits from the SELECT MAJOR SYSTEM menu (Figure 59) without selecting a listed option, the screen showing the functional systems currently in the working file is displayed on the screen. To obtain a blank template for entry of components and parameters from similar systems not contained in the Library, the analyst selects to "add" a functional system to the working file. After entering the add command, a blank Component Maintenance Parameter Template is displayed on the screen.

COMPONENT DESCRIPTIONS

Major System: M60 Tank

Functional System: Command and control display

Component name:	Description:
CRT	Monochrome video display, 8 inch diagonal screen with brightness and contrast controls. Located in Tank Commander control station.
video circuit board	9 inch X 3.5 inch printed circuit board with memory modules and video EPROM display chip. Located in the CPU cabinet.
.	
.	
.	
.	

Press <F2> to see the maintenance parameters for the current component.

Press the up or down arrow keys to highlight additional or previous components.

Figure 61. List of Components in the Baseline Library

Working File Listing of Functional Systems

```
                    Functional Systems

          1.   Armament System
          2.   Engine
          3.   Communications
          4.
          5.
          .
          .
          .
          .


Command (a, m, d, c, s):_

add = add functional system components using a blank template
modify = display existing functional system template
delete = delete a template
copy = copy a template from the Library or another working file
save = save all changes made to this working file
```

Figure 62. Listing of Functional Systems

The analyst will begin the search for similar system maintenance requirements by investigating the currently fielded equipment that the proposed design is going to replace. If the design being evaluated is a modification to the existing system, The analyst may be able to identify other equipment that has undergone the same or similar modifications.

When the new design is so radically different from its predecessor that it can't be used as a baseline for evaluation of the new design, the analyst can examine the functional requirements of systems contained in Army, DoD, and NATO equipment inventories for candidate major systems or functional systems for baseline estimates. The analyst may also elicit input from subject matter experts in the proposed mission area to identify candidate systems to be used for identification of baseline estimates.

When a list of candidate systems has been identified, the analyst will obtain the system design and functional specifications for each potential system. The baseline estimates may be compiled from a single currently deployed system that is very similar to the proposed system. However, it is more likely that the baseline estimates will be a composite of current systems with functional systems or sub-systems that are similar to the proposed system.

When a suitable configuration of functional systems, sub-systems and components has been identified the analyst can enter the component list into blank functional system Templates.

To assist the analyst in obtaining maintenance data on fielded systems not in the Library, we will develop software to allow access to selected military data bases directly from the Component Maintenance Parameter Template. This access will be accomplished through the use of software windows in much the same way that the analyst gains access to the Component Maintenance Parameter Library. DRC currently maintains a direct access link to the Sample Data Collection Data Base.

The component maintenance parameters for existing systems can be gathered from Sample Data Collection (SDC) data, Technical Manuals for maintenance activities, and subject matter experts. Figure 63 shows a Maintenance Allocation Chart from the Technical Manual for M880 Series Trucks. From this chart, the analyst can identify the maintenance action (function), the maintenance category, and the average time to perform the maintenance action. Figure 64 is an example of the kind of data that can be obtained from the SDC data base. Similar output can be obtained by maintenance action or task, maintenance organization, MOS, skill level, etc.

MAINTENANCE ALLOCATION CHART

Table B-1. Maintenance Allocation Chart

C - Crew/Operator O - Organizational F - Direct Support H - General Support D - Depot

(1) Group number	(2) Component/assembly	(3) Maintenance function	(4) Maintenance category C	O	F	H	D	(5) Tools and equipment
01	ENGINE							
0100	Engine	Inspect		.4				
		Test			1.5			
		Service		1.0				
		Adjust		3.7				
		Replace			6.0			
		Repair				A		
	Mount, engine	Inspect		.3				
		Replace			1.5			
0101	Cylinder block	Inspect			6.3			
		Replace				6.3		
		Repair				A		
	Plug, expansion	Inspect		.1				
		Replace			.6			
	Cylinder head	Inspect			4.2			
		Replace			3.9			
		Repair			5.7			
0102	Crankshaft	Inspect			2.9			
		Replace				11.4		
	Seals, main	Inspect			.2			
		Replace			6.0			
	Pulley	Inspect		.2				
		Replace		1.0				
	Balancer, crankshaft (harmonic balancer)	Inspect			.2			
		Replace			1.4			
	Bearing, crankshaft	Inspect				4.5		
		Replace				4.5		
0104	Piston and pins	Inspect				12.0		
		Replace				13.3		
	Rings	Inspect				12.0		
		Replace				12.0		
	Rod, connecting	Inspect				12.0		
		Replace				13.3		
	Bearing, connecting	Inspect				6.2		
		Replace				6.2		
0105	Camshaft	Inspect				7.2		
		Replace				7.2		
	Cover, cylinder head (valve cover)	Inspect		.2				
		Replace		1.1				

A—In this category, no specific times can be established.

Figure 63. Maintenance Allocation Chart

Figure 64. Sample Data Collection Data Base Output

TABLE 11B
SDC AH1SM -- TOP 25 AVUM UNSCHEDULED MAINTENANCE EVENTS
BASED ON MANHOUR TOTAL BY SYSCD WUC. USING 1 EVENTS
FOR 01JAN84 THROUGH 31MAR84

------------------------------AIRCRAFT=FAH1S MODERNIZED COBRA FLIGHT HOUR BASE=2420.1------------------------------

WORK UNIT CODE	TOTAL MAINTENANCE MAN-HOURS	MAINT MAN HOURS PER FLT HOUR	TOTAL MAINTENANCE EVENTS	MEAN TIME BETWEEN EVENTS	% OF REPLACEMENTS	% EVENTS RED X
ENGINE ASSY	281.6	0.12	32	75.63	3	50
MAIN TRANSMISSION ASSY	78.4	0.03	43	56.28	0	35
DRIVE ASSY	71.4	0.03	7	345.73	14	0
MAIN ROTOR HUB	66.8	0.03	58	41.73	0	38
ELECTRONIC INTERFACE ASSY	65.0	0.03	5	484.02	40	0
AMPLIFIER ELCT CONTR SIAS	63.6	0.03	13	186.16	38	0
T/R 90 DEG GEARBOX	62.4	0.03	29	83.45	0	38
MAIN ROTOR BLADE	52.8	0.02	13	186.16	8	38
AMPLIFIER CONT MISSILE COMMD	51.7	0.02	12	201.67	80	8
TAIL ROTOR HUB	45.6	0.02	10	242.01	20	100
TUBE ASSY SCISSOR TO PITCH HORN	45.2	0.02	31	78.07	6	61
AIRFRAME	43.5	0.02	13	186.16	0	0
BLEED ARI HEAT-DEFROST-RAIN RMV SYS	41.8	0.02	50	48.40	2	16
SIGHT UNIT STAB TELESCP	38.7	0.02	26	93.08	12	4
FEEDER	37.7	0.02	7	345.73	29	0
MAIN SKID TUBE	36.5	0.02	9	268.90	86	11
T/R 42 DEG GEARBOX	36.4	0.02	26	93.08	0	38
SKID SHOE	36.1	0.01	15	161.34	80	47
FUEL BOOST PUMP	35.7	0.01	12	201.67	33	83
DUAL TACH ENG/ROTOR RPM IND SYS	35.5	0.01	13	186.16	8	69
SCISSORS & SLEEVE	35.3	0.01	5	484.02	60	0
TORQUE PRESS TRANS	33.8	0.01	28	86.43	79	68
ENGINE OIL PRESS TRANS	33.5	0.01	35	69.15	60	89
CONTROL PANEL TOW	31.5	0.01	6	403.35	80	17
ACTUATOR	28.2	0.01	13	186.16	23	85

Other maintenance documentation such as the maintenance task analysis can be used to determine the MOS and skill level required to perform the maintenance and the type of maintenance (planned or corrective). Maintenance accuracy for diagnose and troubleshoot activities can be generated by examining False Removal Rates from the SDC and other related maintenance data bases. Information on whether or not a failure of a specific component is likely to cause the mission to be aborted can be estimated from examining: 1) system safety data bases that identify components critical to system and human safety, 2) items marked "RED X", and 3) input provided by subject matter experts and analyst judgement.

The standard deviation for the time it takes to perform a maintenance action can also be obtained from SDC data. For situations when data for calculating standard deviations is not available, we will develop some strategies and heuristics for estimating standard deviations of repair times. For example, we could collect data from available logistic support centers to determine standard deviations for some number of maintenance activities performed in different maintenance categories for systems used in different mission areas. With this information, we could calculate the average percentage of the mean repair time for all of the maintenance activities studied. This "percentage of the mean" could then be used as the default standard deviation. The analyst could of course change that value for any particular maintenance action. A slightly inaccurate estimate of the standard deviation will tend to be washed out by modeling maintenance requirements over a long period of time such as a year.

Some of the required component maintenance parameters will probably need to be converted or estimated from the maintenance data. For example, the mean operational units between failure of a component may need to be converted to another metric.

Output

The output of Step 2 is a set of data files of system components and maintenance parameters copied from the baseline library of component parameters for a comparable system or derived from maintenance documentation of similar fielded systems. Each file in the set contains the component maintenance parameters for one functional system within the overall system. Each file will be accessed from the menu of functional systems shown in Figure 62.

User Interface Issues

The user interface for the aid to identifying baseline estimates of system component parameters will consist generally of menus and prompts that will allow the analyst to obtain

of menus and prompts that will allow the analyst to obtain estimates from the baseline library for comparable systems and spreadsheet-like templates for entering and modifying component parameters. Context specific help in the form of definitions, guidelines, and decision aids will be embedded in the software so that the analyst can access additional information for any menu item, prompt or cell entry at all times.

The actual design of menus, selection procedures, and keyboard routines will be developed based on input from intended users, human factors analysis, and the final software design.

4.2.3 Step 3 Identify discrepancies between the government baseline estimates and the contractor's estimates of component maintenance parameters.

Input

Internal - The functional system data files containing both baseline data and available contractor estimates of component maintenance parameters for the proposed system design that were completed in Step 2.

External - Analyst judgment on the amount of tolerance he will accept for deviations between the baseline data and the contractor's estimates.

Process

The performance of this step is dependent on the availability of the contractor's design estimates of at least some of the component maintenance parameters. When the contractor's design doesn't contain any estimates of component maintenance parameters, the analyst will use the baseline estimates as the only input to the simulation model. When this is the case, the analyst can skip this step.

The purpose of this step is to compare the government baseline and contractor estimates for each component maintenance parameter value to identify and produce an MMAA generated list of discrepancies between the two estimates. Whenever possible, we want to take advantage of the fact that many of the components in a new system are not entirely new designs. By comparing the contractor estimated maintenance requirements of new system components to baseline data, the analyst can identify those components that are of the highest risk of inaccurate estimates or those for which insufficient data exists.

When the Component Maintenance Parameter Files contain all of the baseline and contractor estimates, the analyst can have the MMAA sort through each pair of estimates for each component and parameter to identify discrepancies. However, before this is

done, the analyst needs to specify reasonable tolerances for the comparison of values. It is highly unlikely that an exact match will be found for any of the component parameters that contain numeric values such as time or accuracy even when the contractor and the baseline estimates are nearly the same. In other words, the analyst may choose to "accept" (as a non-difference) any time to repair value that is within 10 percent of the baseline estimate.

The MMAA will allow the analyst to specify percentage tolerances for numeric values. Component Maintenance Parameters that consist of textual or coded data such as the MOS, skill level and category will not accept tolerances.

When the analyst is ready to have the MMAA sort one or more of the Component Maintenance Parameter Templates for discrepancies he will return to the IDENTIFY COMPONENT MAINTENANCE PARAMETERS menu and select the "Sort Matrices" option shown in Figure 65. The analyst will have the option to sort and identify discrepancies for a single functional system template or to sort all of the templates currently developed. The MMAA will then sort the two entries for each component parameter for differences. Contractor estimates that are missing will be ignored in the sort.

When a sort has taken place, all discrepancies between each pair of Component Maintenance Parameter estimates are stored in a data file by functional system.

The IDENTIFY COMPONENT MAINTENANCE PARAMETERS menu also has an option to display on the screen or print a list of all identified discrepancies for a single functional system or for all of the functional system files that have currently been sorted.

Output

The results of the sort operation will store a list of differences or discrepancies between the contractor's estimate of a component parameter and the baseline estimate by functional system. Discrepancies that fall within the tolerance specified by the analyst will not appear in the discrepancy list. Functional system files not included in a sort will not be affected by a sort operation.

User Interface Issues

Users will specify tolerances for the identification of discrepancies between Component Maintenance Parameter estimates by selecting options from menus, responding to prompts that appear on the screen and entering information with an input device such as a keyboard or a mouse. For example, Figure 65 is

an illustration of what an IDENTIFY COMPONENT MAINTENANCE PARAMETERS menu might look like.

Identify Component Maintenance Parameters Menu

Identify Component Maintenance Parameters

1. Develop Component Maintenance Parameters
2. Specify Tolerances for Comparisons
3. Sort Matrices
4. Report Discrepancies

Enter a number and then press <RETURN>_

Figure 65. Identify Component Maintenance Parameters Menu

From this menu, to specify tolerances for the sort operation, the analyst would select option 2 (Specify Tolerances for Comparisons). After making this selection, he will be given the option to specify tolerances for all of the functional systems currently defined, a single functional system, or a single component. He will also be given a choice to enter a percentage tolerance by Component Maintenance Parameter or for all parameters.

When the analyst selects option 3 (Sort Templates) a prompt will display on the screen asking the analyst to enter the name of the functional system on which to sort. At this point the analyst could either enter the name of a functional system or the word "ALL". When he enters the word "ALL", all of the functional system files that have been defined will be sorted.

4.2.4 Step 4 Resolve the discrepancies between the government baseline estimates and the contractor's design estimates of Component Maintenance Parameters.

Input

Internal - The Component Maintenance Parameter discrepancy data file created in step 3.

External - The external inputs for resolving Component Maintenance Parameter discrepancies are the following:

- Maintenance Subject Matter Experts
- System design documents including the maintenance task analysis
- System design engineers
- Analyst judgment

Process

When the MMAA has identified and stored discrepancies between contractor and government estimates of Component Maintenance Parameters, the analyst can select the "Generate Discrepancy Reports" option from the IDENTIFY COMPONENT MAINTENANCE PARAMETERS menu to display or print out reports of all discrepancies by functional system and component. The analyst can use these reports as a guide to resolving the discrepancies.

Before the analyst can exercise the computer simulation to obtain maintenance manhour requirements, all of the discrepancies that were identified by the software must be resolved. The following paragraphs describe some of the methods an analyst may use to resolve each kind of discrepancy.

Components for which there are no baseline data - Any new system is likely to contain new hardware or software components for which there are no existing baseline maintenance data. This can occur when the proposed new system has automated a function that was performed by human operators in previous systems. New system components are added to the list of baseline components by the analyst. However, the analyst must still decide whether or not to use the contractor's estimates of the maintenance parameters or modify them based on his her judgement and experience. The analyst may seek to obtain data from other systems that utilize a similar component, get input from subject matter experts, or elicit further information and justification from the contractor. When data from similar systems is unavailable, maintenance estimates can be obtained by conducting motion-time estimation techniques or Human Operator Simulator (HOS) modeling. The mechanisms for making these estimates will be embedded in the MMAA as they were in the WAA (as discussed in Section 4.1.4).

Significant differences between the contractor's estimates and the baseline data - The primary goal of this part of the evaluation is to obtain the best estimate of maintenance requirements for each hardware or software system component for the system design being evaluated. However, it probably isn't necessary for the analyst to spend time analyzing the maintenance requirements for components for which the government and contractor's estimates agree. Unless, of course, the analyst has some knowledge or information that makes him suspect of the baseline estimate. Changing the parameters will always be an option available to the analyst.

In most cases, the analyst will want to identify differences in the contractor and baseline estimates and resolve those differences. As stated earlier, the analyst will be able to specify tolerances for each of the maintenance parameters so that exact matches for data that are very close in value are not required.

Sources of input for resolution of discrepancies may be SMEs, similar system components used in other systems, HOS modeling, MTM techniques, or from details contained in the system design. For example, a difference in the maintenance category or MOS and skill level required may be due to new diagnostic or test features built into the component in the new design. In this case it may be necessary to obtain input from Army design

engineers or engineers involved in the design of the new component. If resolution cannot be reached through these sources, the value can and should be assessed through the formal test and evaluation process which will take place later in the MAP.

Required component parameters missing from the new design - The contractor's design may contain some but not all of the data required for the calculation of maintenance manhours via the simulation model. The design documents may also have reported the required parameter but in a different metric than is available in the baseline data. The analyst can either convert the value to the proper metric, if possible, elicit a new value from the contractor, obtain input from other available sources, or decide to use the baseline estimate.

Whatever process the analyst uses to resolve the identified discrepancies, the Component Maintenance Parameter Templates must be modified to show the best estimate of maintenance requirements per component in the top portion of each cell. In other words, each cell will always contain two parameters: the top portion showing the analyst's best estimate and the bottom portion showing the contractor's estimate.

The simulation model that will determine the total maintenance requirements for the overall system can be executed with either set of component parameter estimates for comparative purposes if the analyst so desires.

Output

The outputs of this step are the Component Maintenance Parameter Files generated from the Component Maintenance Parameter Templates that contains two sets of estimates for the maintenance parameters of each component in the system. One is a set of the best available estimates that could be obtained by the analyst. The other is the set of the contractor's estimates.

Either set of estimates could be used as input for the simulation model of maintenance requirements.

User Interface Issues

The process for generating discrepancy reports is one of menu selection and response to prompts that display on the screen. The spreadsheet-like Component Maintenance Parameter Templates will be used to change the baseline estimates to the best available estimates.

4.2.5 Step 5 Identify and develop parameters for each mission scenario to be analyzed in terms of maintenance manhour requirements, system availability, and system reliability.

Input

Internal - Mission requirements obtained from the System Performance Requirements Estimation Aid (SPREA) in Product 1.

External - Data on mission requirements will be obtained from the Operation Mode Summary and Mission Profile, MAA and MADP results, LSA, and the Army's Sample Data Collection System (see Figure 66).

Process

When the analyst has modified the baseline estimates of component parameters to reflect the best available estimates of component maintenance requirements, he or she will access the maintenance simulation model to define a mission scenario for the computer simulation. The analyst will not need to be concerned with building the model itself or with specifying any of the logic or algorithms needed to simulate the maintenance requirements. The analyst will need to enter the following information to describe the mission being simulated:

1. Simulation period - This is the number of days of maintenance activities to be simulated. Normally this will be one year.

2. Number of missions per day - One of the calculations that is used to determine the total operational units, standby time, and availability of the system for the time period specified for the simulation.

3. Mission length - In order to simulate the amount of operational time for each of the system components, a mean time and standard deviation estimate of mission length will be derived from the external input data sources described in section 4.2.5.1.

4. Mission frequency - Mean and standard deviation values (assuming a normal distribution) are entered to represent the amount of time between missions. This information is used by the simulation model to calculate the cumulative operational units over time. The mission frequency values are also used to establish "windows" within which all maintenance must occur to ensure the availability of the system for any particular mission. For example, if a mission in the simulation is scheduled to begin based on the mission

Figure 66. Sample Data Collection Output of Mission Parameters

TABLE 8
UNC OPERATIONAL STATISTICS FOR AH1SM
FOR THE PERIOD 01JAN84 THROUGH 31MAR84
USING 1 EVENTS -- SORTED BY SYSCD MISSION TYPE
INCLUDES UNIT AND INTERMEDIATE
SYSCD-FAILS MODERNIZED COBRA

MISSION TYPE	TOTAL NUMBER OF MISSIONS	AVERAGE MISSION HOURS	AVERAGE LANDINGS PER MISSION	AIRCRAFT STATUS AFTER MISSION (PERCENT) % RED X	CIRCLE RED X	RED /	RED -	% OF MISSIONS COMPLETED	ABORTED
SERVICE	48	1.01	7.88	8	2	6	0	98	2
TRAINING (GENERAL)	1210	1.06	5.44	9	2	19	0	98	2
TRAINING NOE	1	0.50	1.00	0	0	0	0	100	0
TRAINING INST	4	2.80	9.50	0	0	0	0	100	0
TEST	93	1.04	4.96	17	2	16	0	95	5
OTHER	1	0.40	2.00	100	0	0	0	100	0
ALL TYPES	1365	1.77	5.50	9	2	18	0	98	2

frequency requirements and the required maintenance for the system has not been completed, the system will not be available for that mission. The mission frequency, mission length, and number of missions per day will determine the total number of possible missions.

Therefore, the probability of a system being available can be calculated using the following equation:

prob = 1 - (missions missed/missions possible)

5. Component operational units per mission - The operational units per mission is a value that represents the amount of use a system component receives during a mission. The metric used for this value will vary with each system component and will correspond to the metric that is used in the estimate of mean operational unit between failure (e.g., rounds fired, miles driven, landings, or operational time). The operational units per mission value will be input as a numeric constant that represents either mission averages such as rounds fired or the percentage of time that the component is in use during a mission, on average. Because of the potential variety of missions that may be required of a single system, the operational units per mission will not be included in the baseline Library. For example, the new LHX helicopter currently in the MAP will be designed to perform both attack and reconnaissance missions. The usage of different equipment such as rocket launchers vs. radar components will be different for each mission scenario. These estimates will need to be input by the analyst at the time the other mission scenario information is defined.

   Sources of information for the operational units per mission are: combat models, subject matter experts, and system engineers.

Figure 67 is an illustration of what the DEVELOP MISSION SCENARIO menu might look like.

When the analyst selects the "Component Operational Units per Mission" option from the mission scenario menu, a second menu will display a list of the functional systems within the overall system currently being worked on. From this menu, the analyst can select a subset of components that represent a functional system for which to enter the operational units per mission. When a functional system has been selected, a matrix template similar to the one shown in Figure 54 will be displayed on the screen. The left column of the matrix will contain the list of components that were listed in the Component

DEVELOP MISSION SCENARIO

1. Mission name: Destroy Enemy Vehicles
2. Simulation time span (days): 365
3. Average number of missions per day: 4
4. Mission duration mean time (hours): 2
5. Mission duration standard deviation: .5
6. Time between missions (mean): 2
7. Time between missions (std dev): .1
8. Component operational units per mission

Enter a number and then press: <RETURN>_

Figure 67. Develop Mission Scenario Menu

Major System: M60 Tank	
Functional System: Engine	
Component Name	**Operational Units per Mission**
Fuel Injection	
Cylinder Head	
Crankshaft	
Seals, main	

Figure 68. Operational Units Per Mission Template

Maintenance Parameters Template for that functional system. The analyst can move around in the matrix of cells using cursor control keys to add, modify, delete, and copy operational units per mission values in much the same way one would enter data into an electronic spreadsheet. This process is repeated for all of the functional systems within the overall system.

When all of the mission scenario data has been defined, the analyst can exercise the maintenance computer simulation model to obtain estimates of the total maintenance manhour requirements for the currently defined mission scenario. The aid will also provide the analyst with a mechanism for saving, retrieving, and copying mission scenarios for a particular system. This will allow an analyst to create new mission scenarios without starting from scratch by modifying a scenario that is close to the one the analyst wants to simulate.

<u>Output</u>

The output of this step is a data file of Mission Scenario Parameters for each type of mission required of the system design that is being evaluated. Each mission scenario data file will be used as input for an execution of the Maintenance Requirements Simulation model.

<u>User Interface Issues</u>

The process of defining mission scenario parameters will consist of selecting menus and responding to prompts to access the DEVELOP MISSION SCENARIO menu. When the analyst selects to enter the operational units per mission for system components, he will be presented with a spreadsheet-like Mission Scenario Template similar to the Component Maintenance Parameters Template.

Each mission scenario can be saved, recalled, copied, and modified so that the analyst can easily develop a number of similar scenarios for different missions required of the system being evaluated.

<u>4.2.6 Step 6 Exercise the computer simulation to calculate the maintenance manhour requirements, system availability, and system reliability for each mission scenario.</u>

<u>Inputs</u>

<u>Internal</u> - The Maintenance Component Parameter file developed by the analyst in Steps 1-4 and the mission scenario file(s) developed in Step 5.

<u>External</u> - None

Process

The process discussed here is a description of the activities performed by the analyst to exercise the Maintenance Requirements Simulation Model that is embedded in the MMAA. A detailed discussion of this network model can be found in section 4.3.4.

When all of the Component Maintenance Parameters and Mission Scenario Parameters have been defined, the execution of the Maintenance Requirements Simulation Model is simply a matter of selecting the "Execute Maintenance Simulation Model" option from the DFVELOP MAINTENANCE REQUIREMENTS menu. The system will prompt the analyst to enter the name of the system to be modeled and indicate whether the "best available" Maintenance Component Parameter estimates or the contractor's estimates are to be used.

If any of the required input from the Component Maintenance Parameter or Mission Scenario data files is missing, incomplete, or in error, the software will issue an error message and, if possible, continue execution. If a fatal error is encountered, the execution will terminate. Each error message that is issued during the execution will be stored in a data file that can be viewed or printed out via the Reports Generator that will be discussed in Step 7.

Output

The output of the simulation model will be a data file that will serve as a relational data base of maintenance requirements for the proposed system. The data base will contain:

- Maintenance manhour requirements by:
    - component
    - functional system
    - MOS and skill level
    - maintenance category
    - maintenance type (planned or corrective)
    - maintenance action
- System availability
- System reliability
- Functional system reliability

User Interface Issues

The only user interface involved with executing the Maintenance Requirements Simulation is menu selection and response to system prompts.

4.2.7 Step 7 Evaluate the results of the computer simulation in terms of the maintenance jobs that are required, the tasks that make up each job, the number of maintenance hours required per job, system performance requirements and manpower constraints.

Inputs

Internal - The data file containing the execution results of the Maintenance Requirements Simulation generated in Step 6 of the Maintenance Manhour Analysis Aid.

External - The results of the Manpower Constraints Estimation Aid (MCEA) that is an output of Product 2 and the results of the System Performance Requirements Estimation Aid that is an output of Product 1.

Process

The execution results of the Maintenance Requirements Simulation are stored in a data file that will serve as a relational data base of maintenance requirements information. A Maintenance Reports Generator will be developed to allow the analyst to obtain information from the data base file.

The Maintenance Reports Generator will produce two reports automatically that the analyst will use to determine the overall maintenance requirements for the system design. The first is a Maintenance Manhour Summary Report. This report is a table of information that lists each maintenance job (MOS, Skill level and Category) that is required by the system design. In addition, the summary report will show the maintenance tasks by component and maintenance action, the number of hours spent on each task, and the total number of maintenance manhours for all tasks within a maintenance job designation.

The second report that is produced automatically is the Maintenance Headcount Report. This report will complement the Maintenance Manhour Summary Report by showing the actual number of people required for each maintenance job and the percentage of time that number of people were needed to maintain system availability. Included with this report will be a set of histograms that illustrate the headcount percentages by maintenance job. The analyst will need both the Maintenance Manhour Summary Report and the Maintenance Headcount Reports to accurately evaluate the maintenance requirements for the proposed system design.

The Maintenance Reports Generator will also allow the analyst to ask for any information in the data base cross-referenced with any other data. Following is a list of some of the ways that the analyst can get reports of the data:

- Total system maintenance manhour requirements
- Maintenance manhours by MOS and skill level
- Maintenance manhours by MOS and skill and maintenance level
- Maintenance manhours by component
- Maintenance manhours by functional system (e.g. avionics system, armament, etc.)
- Functional system reliability
- System availability

The analyst can use the Maintenance Reports Generator to display information informally on the screen of his work station for informational purposes or he can define the format of more formal reports of information that is contained in the data base. The Maintenance Reports Generator will also allow the analysis to produce graphic representations of the maintenance requirements data such as a frequency distribution of failures for a particular component or a line graph of the total maintenance manhour requirements over time.

The analyst will compare the output that is obtained from each execution of the model to the AAMH constraints determined from the Manpower Constraints Estimation Aid (MCEA) and to the availability and reliability requirements obtained from the System Performance Requirements Aid (SPREA).

Output

The output of this step is the identification of potential design deficiencies in terms of 1) the estimated manpower required to maintain the system as compared to the manpower constraints and 2) the estimated availability and reliability of the system as related to maintenance requirements compared to the system performance requirements determined in the Product 1 of the $(MPT)^2$ process.

Another output of this Step 7 is a set of maintenance requirements reports that will be used as input for the Trade-Off-Analysis process that will be aided by Product 6 of the $(MPT)^2$ effort.

User Interface Issues

The Maintenance Reports Generator will be a menu and prompt driven software component that can be accessed from the main menu of the Maintenance Manhour Analysis Aid. It will include a logical command structure that will allow the analyst to cross-reference stored data such as maintenance manhours by component and MOS, skill level and category.

The Maintenance Reports Generator will also provide the analyst with a menu and prompt driven interface to specify graphical and statistical analysis of the results of the Maintenance Requirements Simulation.

4.2.8 Step 8 Investigate potential solutions to maintenance deficiencies by modifying Component Maintenance Parameters and re-running the model.

Inputs

Internal - Maintenance workload deficiencies in the system design that were identified in Step 7

External - The contractor's design engineers, subject matter experts, analyst judgement.

Process

When the results of the Maintenance Requirements Simulation model indicate that the manpower required to maintain the system under evaluation exceeds the manpower constraints obtained from the MCEA or that the system availability and reliability requirements obtained from the SPREA are deficient, the analyst can use the MMAA to investigate potential solutions to the design deficiencies. The analyst will be able to obtain, from the Reports Generator, a frequency distribution of component or functional system failures, a list of components or functional systems that caused a mission to be missed or aborted, or other information that may indicate the reason for a maintenance deficiency. Given this information, the analyst can use the MMAA as a tool to estimate the effects of changes in the Component Maintenance Parameters on maintenance workload by modifying one or more parameters and re-executing the simulation model. For example, if the contractor could increase the mean time between failure of a particular component or functional system by 10%, would that change reduce the maintenance manhour requirements enough to meet the manpower constraints? What impact would such a change have on the system availability or reliability? This information can be presented to the contractor for potential resolution of the deficiency.

When presented with a report of maintenance workload deficiencies, the MMAA can also be made available to the contractor for this kind of "what if?" analysis.

Potential solutions that involve increases in personnel skill and performance levels can be passed on to the $(MPT)^2$ Trade-Off Analysis aided by Product 6 to determine the impacts of the solutions on personnel characteristics, training, interface design, etc.

Output

The outputs of this step are simulation results files that contain the same data obtained from the original execution of the Maintenance Requirements Simulation model. These results files can be used by the Army analyst and the contractor to evaluate the effects of potential solutions to maintenance deficiencies on maintenance workload. These results files will also be available as input to the analysis aided by Product 6.

User Interface Issues

The user interface for performing this step will be the spreadsheet-like Component Maintenance Parameter Templates described in Steps 1 and 4 and the interface described in Step 6 for executing the Maintenance Requirements Simulation Model.

4.3 MMAA Software Elements

This section contains a brief description of preliminary designs of the software elements that comprise the Maintenance Manhour Analysis Aid (MMAA). These elements are grouped into the following categories:

1. Templates - consist of sets of menus, prompts, and spreadsheet-like interfaces for users to create and gain access to data files

2. The Component Maintenance Parameter Library - includes historical data on maintenance parameters of fielded military weapon systems.

3. Direct access to military maintenance data bases - consists of software that is included in the MMAA that will give the analyst access to selected data bases that contain maintenance data on fielded systems without leaving the MMAA.

4. Data files - store information specific to the evaluation of a proposed system design. Data files store both input and output data that is used and produced by the other software components.

5. The Maintenance Requirements Simulation Model - is the generic maintenance network simulation model used to calculate estimated maintenance manpower requirements.

Like the WAA, the MMAA will have an Application Manager that is the underlying software operating system that controls the transfer of information between all of the software components.

Figure 69 illustrates the relationships between each of the software elements in the MMAA.

4.3.1 The Templates

The Component Maintenance Parameter Template

This template provides for the following three different functions to be performed by the analyst within the overall activity of identifying the component maintenance parameters of the system under evaluation:

1. It provides the analyst with a menu and prompt driven interface to gain access to and copy information from the Component Maintenance Parameter Library.

2. It provides a spreadsheet-like interface to let the analyst easily copy and modify data obtained from the Library and enter data from other sources.

3. It provides a mechanism for creating, retrieving, and modifying data that is stored in data files.

The Mission Scenario Template

The function of this template is to provide the analyst with a menu and prompt driven interface to create, store, retrieve, and modify mission scenario data files that are used as input for the Maintenance Requirements Simulation Model.

The Mission Scenario Template also provides the analyst with a spreadsheet-like interface to enter the mean operational units per mission data for each component in the system.

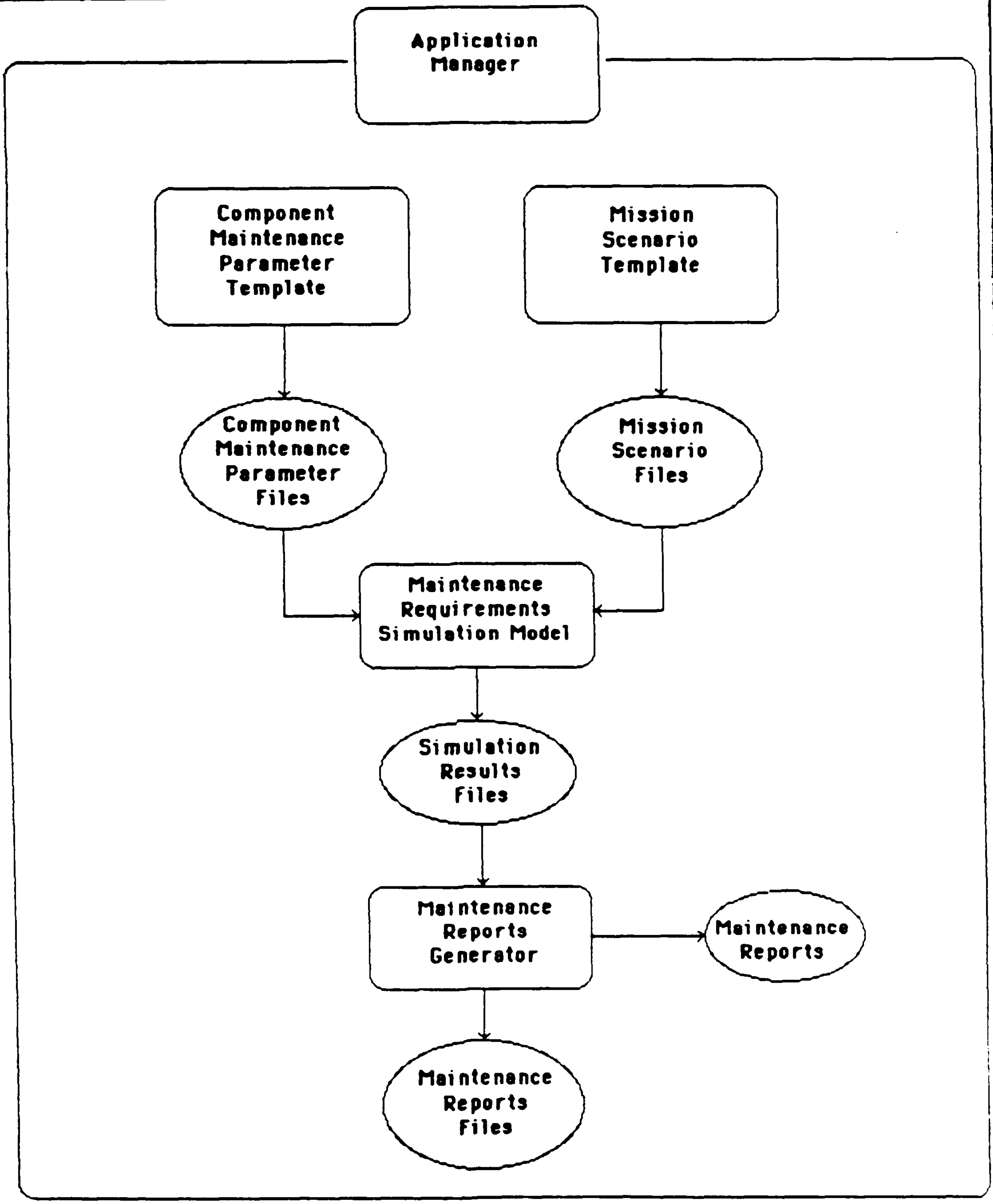

Figure 69. Relationships Between Software Elements of the MMAA

4.3.2 The Reports Generator

This template will be similar to a menu, prompt, and command driven relational data base manager. It will be used by the analyst to gain access to and retrieve data from the Maintenance Requirements Simulation Model results data base. Statistical and graphical analysis capabilities will be embedded within the Reports Generator.

The Reports Generator will let the analyst combine various pieces of data and specify the format, headings, and labels for maintenance manpower requirements reports. The reports can be printed out and saved as documents in maintenance reports data files.

4.3.3 The Component Maintenance Parameter Library

The Component Maintenance Parameter Library is a data base file of maintenance parameters for individual components that make up major systems within the Army. The data base is organized by functional systems within each major system.

The analyst will be able to use the Component Maintenance Parameter Template to locate and copy historical maintenance information on component parameters that are required as input to the Maintenance Requirements Simulation Model. The historical data gathered from fielded systems within the military. The analyst will use this data as baseline estimates of maintenance parameters for proposed system designs that are being evaluated.

Organization of the parameters in the Library by Mission Area, major system category, major system, and functional system will let the analyst build a set of baseline estimates for the system under evaluation from a number of different major systems in the field so that the baseline estimates closely approximate the configuration of components designed into the new system.

It will be impossible, under the scope of this effort, for us to gather component maintenance parameter data from every major system fielded in every Mission Area. However, we will develop and prioritize a list of major systems from each Mission Area and select systems based on the needs of the Army analysts and the practicality of obtaining the data in a time frame that is within the scope of the $(MPT)^2$ effort. We anticipate that we will be able to include Component Maintenance Parameters for at least one major system in each Mission Area. We will also document and transfer the methodology for gathering and entering the data for other major systems into the Component Maintenance Parameter Library.

The sources of data we will use to gather the Component Maintenance Parameter data will include:

- Maintenance task analyses taken from Technical Manuals.
- Maintenance task allocation charts.
- Maintenance MOS and skill level assignments within the different maintenance categories.
- Historical data on average times for different maintenance activities.
- Maintenance logs of component and equipment failures.
- Subject Matter Experts.

Direct access to military maintenance data bases

In addition to the Component Maintenance Parameter Library, the MMAA will contain software that will give the analyst access to selected data bases that contain maintenance data for fielded military systems. The analyst will use this capability when there is no adequate comparable system component in the library.

The information in the maintenance data bases(s) that are selected for use with the MMAA will require more interpretation on the part of the analyst than will the data in the library. This is due to the fact that the data are not a part of the MMAA and are therefore less MMAA specific. However, the scope of information across a broad variety of fielded systems and the fact that these data bases are continually updated with new data makes access to one or more maintenance data bases desirable as a fall-back option to Component Maintenance Parameter Library data.

In Task 2 of the $(MPT)^2$ effort, we will identify candidate data bases for which to develop direct links with the MMAA. One of the most promising candidates will certainly be the Sample Data Collection Data Base. DRC currently maintains a direct link with the SDC Data Base and has developed the software architecture to convert SDC data tapes to a format that is usable for a HARDMAN analysis.

4.3.4 Data Files

Component Maintenance Parameter Files

These files will contain the best available estimates of the maintenance parameters for each hardware and software component

included in the system design under evaluation. If available, these files will also contain the contractor's estimates of component maintenance parameters. A Component Maintenance Parameters file is created by the analyst either by copying component parameters from the Component Maintenance Parameters Library or by entering components and parameters directly into the Component Maintenance Parameters Template. A description of each maintenance parameter included in the file can be found in Table 4.

The Component Maintenance Parameters file is a required input for the Maintenance Requirements Simulation Model.

Mission Scenario Files

The analyst creates Mission Scenario files from the Mission Scenario Template. Each Mission Scenario file contains information on specific missions that the system under evaluation must perform. This file is a required input for the Maintenance Requirements Simulation Model. A detailed description of the contents of the Mission Scenario file can be found in Section 4.2.5.

Simulation Results File

The Simulation Results File contains all of the results of the execution of the Maintenance Requirements Simulation Model. This file actually serves as a relational data base file. The final values of all of the variables and arrays that keep track of the cumulative maintenance requirements in the simulation model are stored in the Simulation Results File. It will serve as the input file for the Reports Generator software component.

A detailed description of the contents of the Simulation Results file can be found in Section 4.2.6 and in the discussion of the Maintenance Requirements Simulation Model in Section 5.2.4.

Maintenance Reports Files

When the analyst has executed the Maintenance Requirements Simulation Model and used the Reports Generator Template to create various reports of maintenance requirements, each report can be saved as a Maintenance Report File. These files are simply copies of reports that were generated. They are text files that can be edited with a word processor or text editor but they can't be recalled and modified with the report generator. Maintenance Reports files are a convenient method of storing reports.

4.3.5 The Maintenance Requirements Simulation Model

The Maintenance Requirements Simulation Model that is embedded within the MMAA will model the maintenance requirements of each component in the new system being evaluated and will compute an estimation of the total system maintenance requirements and an estimation of system reliability and availability. Figure 70 is a block diagram of the top level network in the Maintenance Requirements Simulation model. The next few pages will explain the logic, algorithms, and data collection techniques used in the model at a conceptual level. All of the techniques and concepts described herein are within the current functional capabilities of the Micro SAINT simulation software that will be used to build the embedded computer model.

Each oval or rectangular shape in the illustration represents a task in the top level network. The arrows between the nodes indicate the sequence of execution. The simplicity of this top level network is apparent. However, the rectangular node labeled "perform maintenance" represents a sub-network of tasks.

The following paragraphs discuss the individual tasks in the model.

Task 1 - Calculate Maintenance Schedule

The task labeled 1.0 will calculate the number of operational units before the first failure requiring corrective maintenance for each component in the system being evaluated. This will be accomplished by a Micro SAINT function that will search the component parameter matrix that was input by the analyst for each maintenance action whose "type" is "corrective". The function will then calculate an exponentially distributed random number using the "mean operational units between failure" for that action and component. The actual number of operational units to be used for the simulated first corrective maintenance for each component will be stored in a two-dimensional variable array along with the binary value from the Component Maintenance Parameter matrix that indicates whether or not that particular component failure is critical enough to cause the mission to be aborted. The current number of operational units at this point in the simulation (at this point zero) will also be stored. The last element for each component in the array is a binary value that indicates when the current number of operational units has reached the value calculated for the first component failure. Figure 71 is an illustration of the elements in the corrective maintenance array.

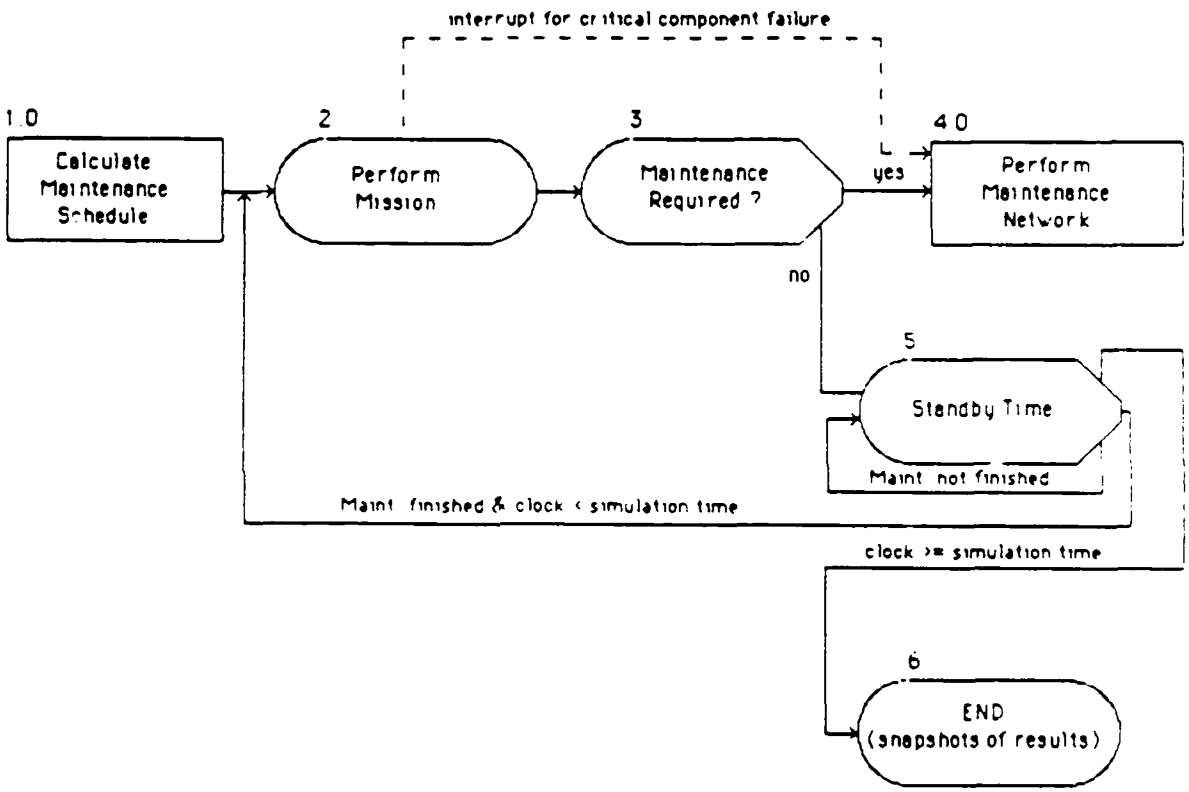

Figure 70. Top Level Network in the Maintenance Requirements Simulation Model

Name	operational units this mission	maintenance required	critical component
Component 1	23	1	0
Component 2	16	0	1
Component 3	18	0	1
Component 4	12	1	0
Component 5	100	1	0

Figure 71. Corrective Maintenance Array

A second variable array will contain values to be used for simulating planned maintenance. The number of operational units between maintenance actions that are "planned" will be taken directly from the component matrix since planned maintenance is scheduled on a regular basis. The variation in the time that planned maintenance is actually conducted is modeled by performing planned maintenance only between missions. This array will also contain an element that indicates the current number of operational units since the last occurrence of this planned maintenance action and a binary "flag" (1 or 0) to indicate when the component is ready for the planned maintenance.

<u>Task 2 - Perform Mission</u>

The function of this task is to increment variables that indicate the current state of the simulation model. Following is a list of variables that are incremented in task 2:

1. A counting variable that keeps track of the number of missions started is incremented by one.

2. The number of operational units for each component per mission according to the mission scenario information that was entered by the analyst.

3. The mission mean time and standard deviation are used to calculate a normally distributed random number representing the actual (simulated) execution time for "Perform Mission".

4. The "current number of operational units" elements of the maintenance schedule arrays for planned and corrective maintenance (discussed above) for each component are incremented by the number of operational units per mission obtained from the mission scenario data. For example, if the mission scenario data indicates that a component is operated for 50% of a mission, and the simulated mission time is 2.5 hours, the current number of operational units for that maintenance action is incremented by 1.25 units.

5. For planned and non-critical corrective maintenance actions, the current number of operational units is compared to the number of operational units for the next failure (or planned maintenance). If the current operational units is greater than or equal to the value for the next failure, the flag element indicating a need for maintenance is changed from 0 to 1.

Corrective maintenance that causes the mission to be aborted will cause task 2 to be interrupted and the maintenance will be performed immediately (refer to the dotted line on the network diagram). In this case, the operational units per mission for the other components in the system will only be incremented by the percent of the mission that was completed.

6. When a mission is aborted, a variable counting the total number of aborted missions is incremented by one. The value of this variable will be used to calculate a measure of the system reliability using the following equation:

$$\text{reliability} = (TS - TA) / TS$$

where:
TS = total missions started
TA = total missions aborted

Reliability in the above equation is the probability of the mission being completed without aborting.

Task 3 - Maintenance Required ?

This is a zero time task whose function is to sort through the variable arrays to determine if any of the planned or non-critical maintenance flags are equal to 1 (one). Task 3 is a decision task. If any of the component flags equals one, it is followed by the "Perform Maintenance" network and by the task labeled "Standby Time". This is to establish a "window" of time within which all maintenance must be completed to avoid missing the next scheduled mission.

If all of the component flags in the two variables are equal to 0 (zero), only task 5 ("Standby Time") is executed next.

Sub-network 4.0

This sub-network simulates the performance of all maintenance activities. The maintenance for each component whose "flag" in the planned or corrective maintenance variable array is performed in parallel. To calculate the actual number of people needed for each maintenance job, the model will first generate the maintenance times for each task and then sum all of the tasks that are to be performed by a single maintenance job. This value is compared to the time allotted for the maintenance window to determine the number of people needed for each job. Figure 72 is a block diagram of the tasks in the "perform maintenance" sub-network.

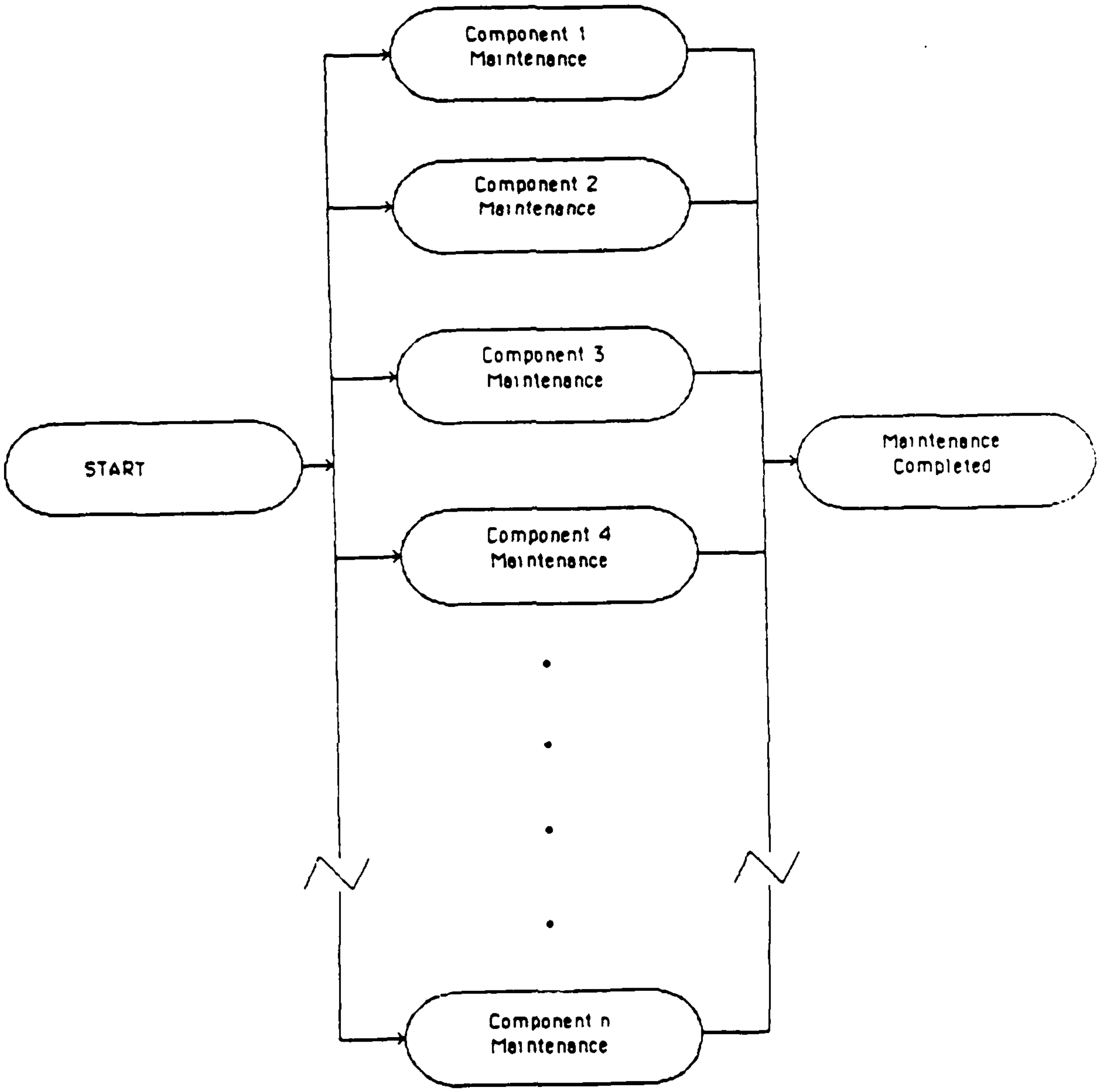

Figure 72. "Perform Maintenance" Sub-network

When the maintenance for a component has been completed, the variable array element containing the cumulative operational units between maintenance is re-set to zero. If the corrective maintenance was performed, a new exponentially distributed random number is generated for the number of operational units until the next failure and assigned to that array element in the corrective maintenance array.

Task 4.1 is a "dummy" task used to start each of the component maintenance tasks that have flag values equal to 1 (one). Task 4.1 also assigns the value of 1 (one) to another flag (referred to later as the "overall maintenance flag") indicating that maintenance (of some kind) has started. Task 9999 will not execute until all of the maintenance tasks have completed. It is a zero time task that resets the maintenance flag to 0 (zero) to indicate that all maintenance has been completed.

The time it takes to perform each individual maintenance action is a normally distributed random number that is calculated from the mean and standard deviation values for repair times that are in the Component Maintenance Parameter File. The calculated time is also used to increment the variables that represent the cumulative number of manhours for the appropriate:

- Maintenance job (MOS, skill level and category).
- Maintenance type.
- Maintenance level
- System component

<u>Task 5 - Standby Time</u>

This task simulates the time between scheduled missions. It follows task 3 whether or not maintenance is required. The execution time for task 5 is generated from a function that uses the following mission scenario values:

- Mean time between missions
- Standard deviation between missions
- Number of missions per day

The main purpose for the "Standby Time" task is to establish "windows" of time within which all maintenance must be completed without missing the next scheduled mission. At the end of task 5

the value of the "overall maintenance flag" is checked. If the value of the flag is 1 (one), it indicates that some maintenance is still being performed.

When this is the case two things happen:

1) A variable storing the number of missed missions is incremented by one.

2) A new window is established by generating an execution time for the mission that was missed and adding it to another randomly generated standby time.

Task 5 keeps following itself until all of the maintenance has been completed. Then it is followed by the performance of the next mission. The number of missed missions is used to calculate a measure of the system availability at the end of the simulation using the following equation:

availability = TM / (TS + TM)

where:
TS = total missions started
TM = total missions missed

When the system clock is greater than or equal to the number of days covered by the simulation, as indicated in the mission scenario data, task 5 is followed by the last task in the model.

When the last task is executed, the values of all of the variables used to store maintenance manhour requirements will be stored in a Simulation Results File data base. The analyst can access this data base through the Maintenance Reports Generator to generate reports of the maintenance manhour requirements calculated in the simulation model.

The output of the computer simulation model will be a relational data base of maintenance manhour requirements that can be queried to report various combinations of maintenance requirements such as:

- Maintenance jobs required.
- Maintenance tasks (maintenance action by component) per maintenance job.
- Manhours by maintenance job.
- Maintenance headcount data per job.
- Manhours by system component.
- System reliability.

- Component reliability.
- Functional system reliability.
- System availability.

4.4 Estimated Analysis Time

Based on the maintenance requirements analysis that is defined in this section, we anticipate that a range of 40 - 80 hours of analyst time will be required for a typical major system acquisition.

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CONCEPT FOR A DECISION AID TO EVALUATE SYSTEM DESIGN MANPOWER REQUIREMENTS

Eleanor Criswell, Dennis Faust and Mike Smith
Science Applications International Corporation

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CONCEPT FOR A DECISION AID TO EVALUATE SYSTEM DESIGN MANPOWER REQUIREMENTS

PROJECT OVERVIEW

Project Requirement

The Army Research Institute (ARI) has initiated a three phase program to develop six decision aid products for implementing the Army's MANPRINT (Manpower Personnel Integration) program. This submission responds to the first phase of the requirement: development of a detailed concept paper. Specifically, the present paper addresses only Product 5 -- a decision aid to evaluate the manning requirements (estimated crew size) for a system given the initial system design. This product will support manpower, personnel, and training decisions concerning whether or not to commit to system development.

The MANPRINT Tools Research and Development Program

The purpose of this ARI research program is to design, develop and produce six MANPRINT decision aiding products. It will be useful to first describe the nature of the intended products of the program. Figure 1 i' provided as a reader's reference for this overview.

Products 1 to 4 of the program involve the pre-design phase of system development. These products are intended to influence system designs. Product 1 focuses on defining system requirements, including system performance criteria and reliability, availability, and maintainability requirements. Should the six tools be developed and become institutionalized, the front end analysis output of Product 1 could be instrumental to all subsequent products.

Products 2, 3 and 4 are also intended as designer decision aids. They develop pre-design estimates to help identify constraints which may affect the design process. Product 2 estimates maximum crew size, Product 3 estimates limiting soldier characteristics, and Product 4 focuses on likely available training for new system personnel.

Products 5 and 6 are to be implemented once an initial system design is available. These products are intended to evaluate system designs. Product 5 (the subject of this paper) will cluster system performance tasks into required jobs and identify the crew size needed to operate and maintain the system. With it, a user will also be able to determine whether a predetermined crew size can meet system performance requirements. With the output of Product 5, Product 6 will determine personnel characteristics required to fill operator and maintainer crews and identify any deficit between required and available personnel.

There is an evident logic in the relationship among these products as they flow from aiding the design process to aiding the decision to commit to

PRODUCTS:	1	2	3	4	5	6
	SYSTEM PERFORMANCE CRITERIA	MAXIMUM CREW SIZE	LIMITING SOLDIER CHARACTERISTICS	PROBABLE TRAINING ESTIMATE	PREDICTED MANPOWER REQUIREMENTS (CREW SIZE)	PERSONNEL CHARACTERISTICS REQUIRED
PURPOSE:	AID DESIGN PROCESS				R&D DECISION AIDS	

Figure 1. The 6 MANPRINT Decision Aids.

system development. Yet, they must be able to operate as independently as possible and be convenient to use. These products will help the Army insure that its soldiers will be able to operate and maintain system hardware and software in required numbers and at levels of performance that will ensure mission success.

Product 5 Overview

The purpose of Product 5 is to serve as a research and development commitment decision aid once an initial engineered system design becomes available. Specifically, Product 5 is to be a tool capable of determining crew size by refining task clusters into crew operator and maintainer jobs. The tool will support both predictive and prescriptive interests. The primary function of the system is to predict the minimum number of personnel required to achieve intended system performance. The user will be able to answer the question "how many people are required to operate and maintain this system, and what are the tasks in their jobs?" A user will also be able to use the tool to determine the job activities of each member in a crew of a given size. For example, a user could answer a question such as "Could a crew of 2 man the system?" Further, the user of this MANPRINT tool will be able to determine manpower requirements as a function of variables such as criteria or conditions under which performance occurs. This will permit the engineered design to be explored for cost-effective manning/ design alternatives and prospective effects on system performance.

Product 5 will first define mission-function performance objectives and system tasks required to attain the objectives. Through statistical analysis, these data will be reduced to task "clusters" representing system operator and maintainer operations to be performed. The tool will then convert the organized task clusters into distinct jobs to determine minimal crew size. These processes are shown in Figure 2, along with input data required and the intended output.

Before addressing the methodology of Product 5, it is appropriate here to conceptualize the product's envisioned form. Product 5 is envisioned as a computer based system. It is known that ARI would prefer a computer-based tool that could be accommodated on a personal computer, such as the IBM-AT, in order to encourage convenient implementation and wide spread use of Product 5. The AT form of computer with the new gigabyte memory cards and a 20 - 30 MB hard drive is an entirely feasible medium for the proposed decision aid. Largely, the system will be a data base management system with convenient but powerful editing capabilities. It will also possess specific statistical analysis and data manipulation routines yielding fully interpreted output. The Product will be able to forecast crew size and alter input variables in exploratory fashion for advanced applications.

It is expected that the software program will be menu driven. Input data will be keyed in or, if available on tape, read in. Input data requests, processing rationale, and output should be logical and comprehensible for MPT personnel. As regards user training, our preference is for a system that is primarily self-taught (on-screen help and user manual), supplemented with periodic user workshops and newsletters which

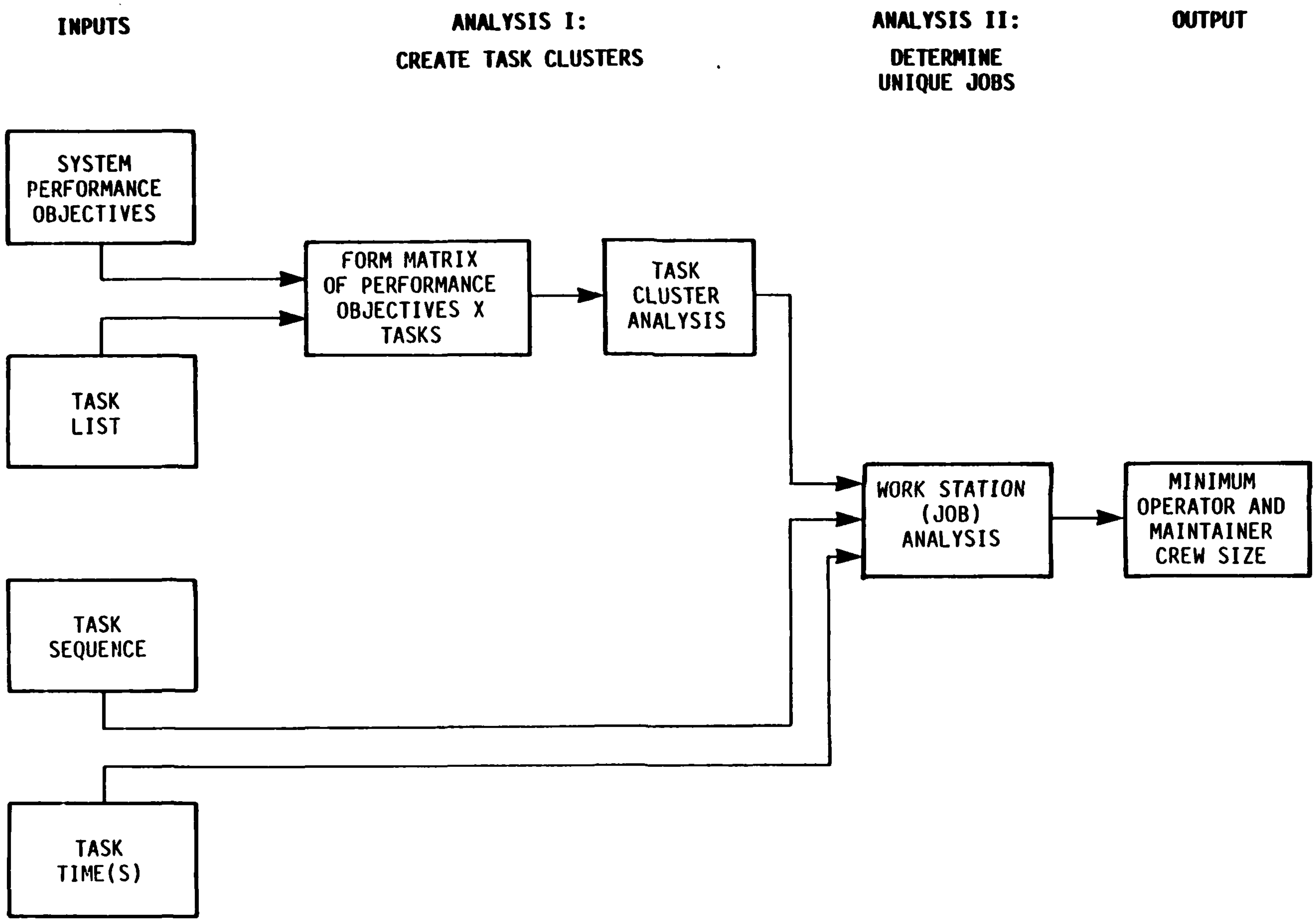


Figure 2. Product 5 Components and Process.

share user techniques and solutions to analytic problems, in the spirit of special interest "user groups."

Uniqueness of This Approach

The Product 5 approach described in this concept paper is based around two features: user-friendliness and comprehensiveness in the concept behind the algorithms. The approach can be described as a "friendly task-clustering precedence-network" analysis.

The product is friendly in several aspects. First, a user can become as involved as he or she wants in the process. A user may input very detailed free text data gathered from a number of sources, may input data from system-stored templates, or may select system defaults. Second, the user can stop the product's process following task-clustering (the first algorithm application), obtain a printout, and review the data before going on to the precedence-network analysis (the second and final algorithm application). The user can also omit this step if desired. Third, the experienced user can conduct advanced applications using the product by manipulating input data to assess its affects on crew size. Fourth, the system will be menu-driven. User requirements will be translated into easy-to-use and understand interfaces. In summary, the system allows the interested user to become involved in the process, but can also provide output with minimal input from the user.

The concept behind the algorithms of Product 5 represents a new level of comprehensiveness in generating manpower estimates. Product 5 associates tasks with system performance objectives, and then clusters similar tasks. Only then does Product 5 create unique jobs using a network or precedence analysis. Previous approaches have created jobs from tasks based largely on time and precedence using work flow process diagrams, without regard to the relation of tasks to system objectives or to other tasks.

Concept Paper Outline

This paper presents the technical approach in eight sections. First, the product's outputs are discussed to give a reader a clear indication of the product's goals. Next, input data requirements and data sources are described. The user will need access only to standard government documents. It will be seen that the product will produce output which increases in quality with the quality of the input data. Thus the product can be used at several points in the materiel acquisition process. The section on process and algorithms describes the system in two steps: the formation of task clusters, and the definition of jobs from task clusters. Next, user services are described. These include the time required for the user to generate an output, embedded training for the user, and a user acceptance plan. Finally, general plans for product development and institutionalization are presented.

OUTPUT AVAILABLE FROM PRODUCT 5

Product 5 employs a two-step process of data analysis. First, similar tasks are clustered, and second, jobs are formed. The terminal output is the result of the second step. Intermediate outputs are produced during the first step.

Terminal Output

Product 5 produces one primary terminal output: the number of jobs required to operate and maintain the system, the tasks to be performed by each person, and task times. The output will summarize the quality of the input data and advise the user how to improve the manpower estimate. The user can obtain this output in three contexts: (1) under expected conditions of system operation, (2) under changes in expected operating conditions, and (3) under contrived operating conditions for sensitivity analysis. These contexts are described below.

The first context for Product 5 output is under normal operating conditions. In this context the user can answer the question "how many operators and maintainers are required to man this system, under normal or expected operating conditions and what are the tasks in their jobs?" In this case, the user will input data which reflect the most probable system operating conditions, given the available documentation. The system will provide the "best" configuration of jobs and tasks, based on task similarities and optimal resourse allocation algorithms. In addition, alternative job configurations which meet the same system requirements, if any, will be provided. These alternative configurations would be derived by "shuffling" the tasks.

The second context for Product 5 output is under changed operating conditions. The user could use this output to answer questions such as "will night time operations increase manpower requirements?" The user enters these conditions as input data. Using this example, the user could simply change day time conditions previously entered to night time, and run the system again. The system will list the jobs which would result from changes in mission timeline, production output rates, and frequency of task occurrence. Stress (increases in system demands) added to system performance affects the job configurations, and the proposed system will produce output sensitive to those factors.

The third context for Product 5 output is to answer a question such as "can 3 people operate the system under normal conditions, or will their task loads be too great?" The Product 5 user can manipulate input data in order to cause changes in the output in order to conduct sensitivity analyses. The system will not work in reverse, that is, the user can not input a given crew size, but the user can change any of the four product inputs (system performance objectives, task list, sequence, and times) until the output shows the crew size of interest. In addition, task to job allocations will be made such that a worker will meet or at least minimize deviation from performance requirements.

Intermediate Ouput

The user can request printouts (or on-screen reports) at intermediate points in the process. The user may request a printout of all data entered: system mission, system performance objectives by component, associated tasks, sequenced, with times. The user may also request the matrix of "system performance objectives" by "tasks" which is developed by the user with help from the system. Creating this matrix is the first step in the Product's 2-step process. The user may wish to examine the matrix before processing continues, and make changes as needed.

The user may also request the actual task clusters produced by the system, although they may not be of interest to many users. From these clusters unique jobs are formed in the second step of the system's process.

INPUT DATA REQUIREMENTS AND DATA SOURCES

Product 5 Use During the Acquisition Process

It is instructive to describe when in the materiel acquisition process Product 5 is used to greatest effectiveness. Figure 3 shows that the first use of Product 5 occurs when early design documents are available. As more information becomes available, Product 5 may be used again and again to determine if the system's manpower requirements are acceptable.

In the spirit of the MANPRINT program, the most important uses of Product 5 occur before the decision about funding prototype development. During this time, Product 5 output is used to evaluate the new system's acceptability in the area of manpower requirements. With Product 5 output, the Army can order system design changes before the system is built. However, Product 5 may also be used after the prototype funding decision to assure that actual system manpower requirements match projected manpower requirements.

Input Data Required from the User

As shown earlier in Figure 2, the inputs required by Product 5 are:

1. system performance objectives
2. list of system tasks for operators and maintainers
3. the sequence of system tasks
4. task times for each operator and maintainer task

Product 5 evaluates the manpower requirements of a system design, and all of these data are part of a system design.

Figure 4 summarizes the four input data requirements and data sources. Each data requirement and its sources are discussed in this section.

System designs mature over time. Data available early in system design are general and of a draft nature. As analyses continue, more detailed data become available. Government requirement documents and analyses undergo iterations. When a system is fielded, actual test data are available. As shown in Figure 5, Product 5 manpower estimates improve with the quality and completeness of the input data. The figure shows a steep then a shallower increase in output quality. Figure 5 also shows that Product 5 can provide manpower estimates early in the system design process.

Product 5 is designed to accept input data ranging in quality and quantity. Thus, a user can obtain an output from Product 5 at a number of points in system design development. Of the four input data requirements, system performance objectives, system tasks, and task sequence are specific to the particular system design under study. The user may obtain design documents with these data, or could enter any objectives, tasks, and sequences desired. Data on task times are less dependent on the nature of the system under study and are difficult to obtain from design documents

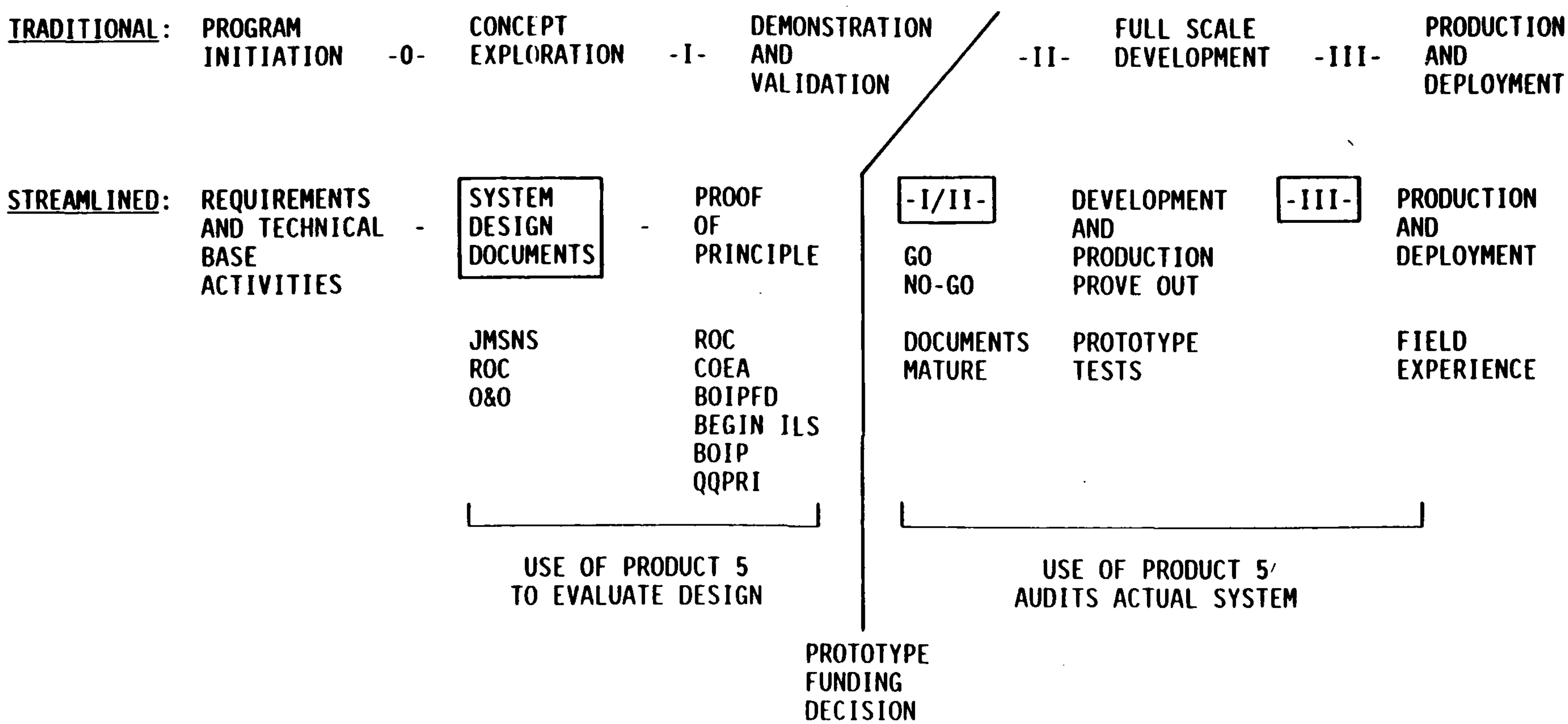


Figure 3. Product 5 Use in Materiel Acquisition Process.

DATA REQUIREMENTS:	PERFORMANCE OBJECTIVES	TASK LIST	TASK SEQUENCE	TASK TIMES
SOURCES AVAILABLE EARLY:	• JMSNS • O&O PLAN - ACQUISITION PLAN - TEMP • DRAFT ROC	• BOIPFD • QQPRI • NETP	• JMSNS • O&O PLAN • ROC • NETP	
SOURCES AVAILABLE LATER:	• COEA • ROC • ILS DOCUMENTS	• BOIP • ILS DOCUMENTS	• GOVERNMENT STUDIES • ILS DOCUMENTS	• GOVERNMENT STUDIES • ILS DOCUMENTS
OTHER SOURCES:	• KAPLAN/CROOKS TAXONOMY • SMEs • PRODUCT 5 USERS • CONTRACTOR-DESIGNER	• SMEs • PRODUCT 5 USERS • CONTRACTOR-DESIGNER	• SMEs • PRODUCT 5 USERS • CONTRACTOR-DESIGNER	• PRODUCT 5 TASK TIME DATABASE • SMEs • PRODUCT 5 USERS • CONTRACTOR-DESIGNER

Figure 4. Product 5 Data Requirements and Sources.

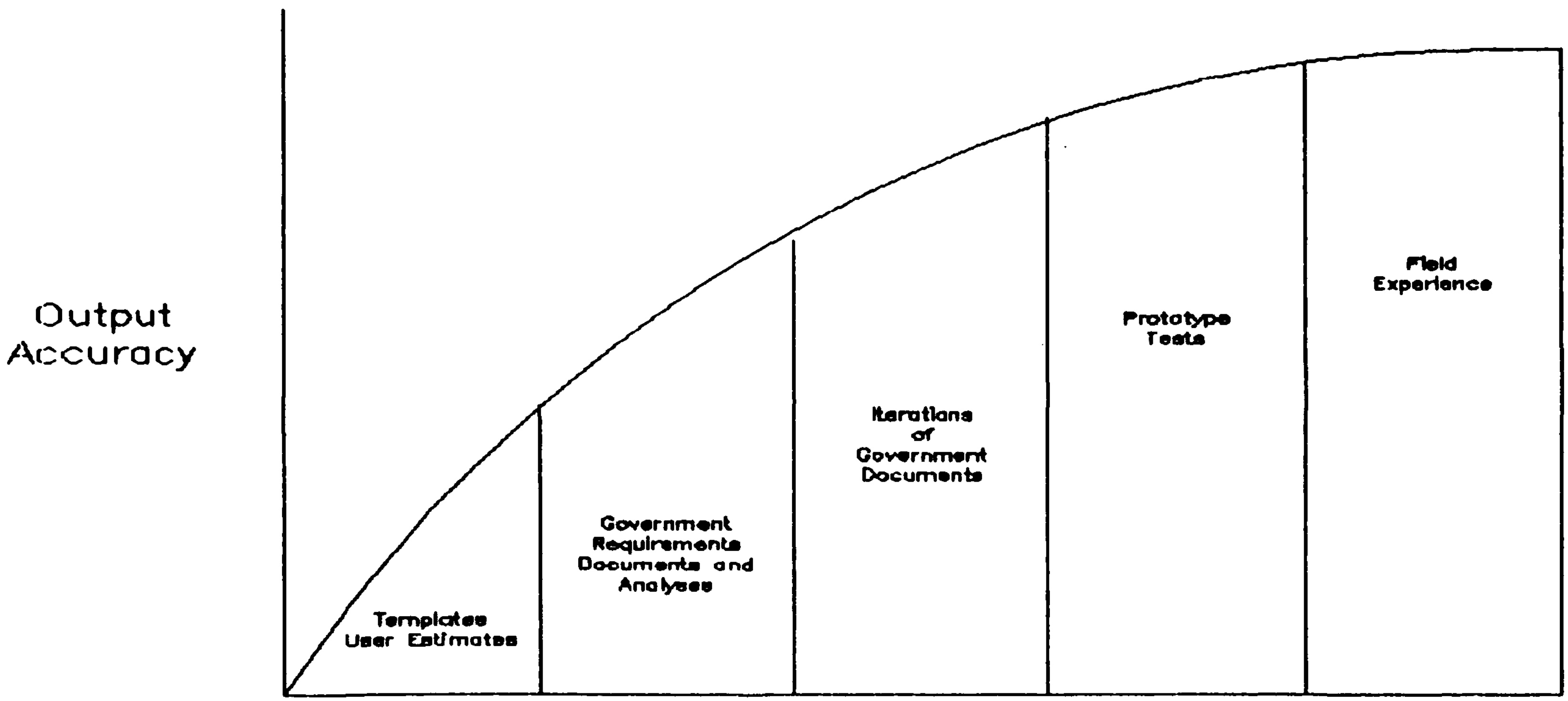


Figure 5. Product 5 Output Accuracy Relates to Input Data Quality.

until late in system design development. Therefore, Product 5 will contain a hard-wired data base of task times to be used as a default if the user does not have task time data.

Macro-Structures for Input Data

It is expected that input data available to the Product 5 user in system design documents will take many forms. Some data will be inaccurate or missing. Over time, system design documents as well as the output from Product 1 may come to provide the Product 5 user with immediately usable data. However, at least the first several cadres of Product 5 users will require assistance in entering data in the correct formats. For example, system performance objectives must be stated in terms of their goal statement, conditions of performance, and performance criteria. Guidance for entering this information (e.g., Mager's 1975 guidelines) will have to be applied during input. To do this, the program will present prompts which aid the user to enter each part of the performance objective in acceptable form. Likewise, a structured "help/prompt" rcutine will be employed for entering the task list, task sequence, and task times. This structured approach will make evident to the user where needed details are absent and further input data are required.

A second structuring mechanism will be used by Product 5. This structure will assist the Product 5 user enter performance conditions and task data, which could be vague or absent from initial system design. Kaplan and Crooks (1980) developed a "task template taxonomy" which may be used to delineate tasks and system performance conditions when these data are needed but missing. The taxonomy is presented in Appendix A. (A similar taxonomy is presented in Kaplan, Crooks, Sanders, and Dechter, 1980).

The Kaplan/Crooks taxonomy catalogues system functions within system missions and permits the user to identify tasks which reflect what the function must accomplish for both operator and maintainer roles. The taxonomy provides the Product 5 user with a front-end analysis based on system missions without regard to MOS. The taxonomy also provides a comprehensive range of conditions under which a system might operate. To solve the problem of vague or absent task and performance objective information, it is proposed that the Kaplan/Crooks taxonomy be automated as a macrostructure for Product 5. The template is general, and for example, describes tasks, not subtasks. The template should be adequate, however, for the decision aiding purposes of Product 5. The user will be directed through the Kaplan/Crooks taxonomy to retrieve tasks descriptive of the system mission and function.

It is proposed that the Kaplan/Crooks taxonomy also provide structure to the performance conditions data. The conditions list contained in the taxonomy is comprehensive. The user could review mission/function statements and search the list in menu fashion to makr all relevant conditions which apply. The process can be easily accommodated on the PC-AT.

Input Data for System Performance Objectives

Data on system performance objectives are available from at least four sources. These source documents, listed in order of their chronological availability, are the (1) Justification for Major System New Starts, JMSNS, (2) the Operational and Organizational Plan, O&O, (3) the Required Operational Capability document, ROC, and (4) documents from the Integrated Logistics System. Each document is described below. Examples of some of the documents are presented to give the reader a sense for the level of detail available in the documents.

Justification for Major System New Starts. The JMSNS is a requirements document developed by the TRADOC combat developer, with input from the material developer, training developer, manpower and personnel planner, and logistician. The JMSNS identifies and supports the need for a new or improved mission capability when it may cost more than $200 million in research, development, test, and evaluation or $1 billion in procurement (FY 80 $). The document provides required system performance objectives which can be used by the Product 5 user. The documents are stored at the respective TRADOC proponent. Once a JMSNS is approved, design development continues. The information in a JMSNS is similar to the information provided by the O&O plan described below.

Operational and Organizational (O&O) Plan. The O&O plan is generated for all systems, major and non-major. This document is generated and approved before the system Project Manager and Project Manager Office are designated, but the O&O plan is improved iteratively. The O&O plan is written by a special task force, special study group, or acquisition team at the TRADOC proponent. The O&O plan describes how the system will be used, where it will be used, weather and climate considerations, battlefield conditions, and the types of units that will use and support the system.

The Test and Evaluation Master Plan, (TEMP), included in the O&O plan, describes the new system performance objectives and system mission, and outlines the developmental and operational test plans. The TEMP is an important document and contains useful information for the Product 5 user. Excerpts from TEMP for the M109 howitzer improvement program an presented in Appendix B to show the reader that Product 5 input data can be extacted from the document. For example, in the area of mission performance, Issue #1 in the TEMP shown in Appendix B is "Is the fire support provided by the HIP responsive? The goal, conditions, criteria, and source of data are provided. In this case, the goal is "to provide fire support for maneuver forces." The conditions are "both open and close configurations, and in its backup manual mode of operations for emplacement, lay, and firing." The criteria are "upon receiving a call to fire from a target acquisition source on fire commands from a fire direction center, the median time for an emplaced HIP to fire the initial round of the mission must be less than 30 seconds, or 45 seconds for high angle missions." The TEMP in Appendix B addresses 14 issues with similar specificity.

The Concept Formulation Package of an O&O plan consists of Trade-off Analyses (TOA), Trade-off Decision (TOD), and Best Technical Approach (BTA), which are prerequisite to the Cost and Operational Effectiveness Analysis

(COEA), which is also part of the Concept Formulation Package. The COEA is one of the major documents involved in making the prototype funding decision. The COEA will provide the Product 5 user with the tasks and missions to be performed, threat and conditions under which the task must be performed, and the logistic support concept.

Section III, "Operational Deployment" of the O&O plan presents system performance objectives. The goals and conditions are also contained within this section. Pages from this section of an O&O plan for the Howitzer Improvement Program are presented in Appendix C. The reader will see that goal and conditions data are available. In this example, the goal statement is "The HIP is operationally deployed to provide direct support fires to committed units within the division sector." The condition statement is "HIP units are normally deployed in firing platoon position areas with support centralized in a battery support area. Platoon position areas will be 1000 to 4000 meters apart."

Performance criteria can be found in the "Operational Mode Summary/ Mission Profile" section of an O&O plan. Samples pages from the HIP O&O plan are found in Appendix D. For example, a criterion statement is "For a sustained rate of fire which is expected to be the operational mode 40-50% of the time, the following ranges are estimated: Mobility, 4-10 moves per day (wartime), 10-25 km; Firepower: 25-75 missions, 100-300 rounds; and Communications, 1-3 hours transmit, 2-6 receive. This is the type of information that can be used by the Product 5 user.

Required Operational Capabilities (ROC) Document. The ROC is developed by TRADOC shortly after the O&O plan is developed. The ROC provides the least essential system performance objectives in the areas of operations, reliability and maintainability, technical, personnel and manpower, training, safety, health hazards, human factors engineering, logistics, and cost. These performance objectives must be approved before production begins. Similar to other design documents, the ROC is developed iteratively. Appendix E contains the outline used for the ROC. Goals and conditions are described in Section 4. Criteria in terms of bands of performance are listed in Section 5.

Documents from the Integrated Logistics Process (ILS). The ILS process produces documents which may be of value to the Product 5 user later in the materiel acquisition process. For example, the "Functional Requirements Identification" document provides system performance criteria. Although work on ILS documents begins during the proof of principle phase, these documents are generally not well developed until after the prototype funding decision is made. The ILS documents are generated and housed at the AMC sponsor.

Input Data for Task Lists

As was the case with system performance objectives, task lists for operator and maintainer functions are provided in a number of documents which improve in specificity over time. The documents are described below, in chronological order of their availability.

Qualitative and Quantitative Requirements Information (QQPRI). The QQPRI is a document that improves iteratively. It is generated (in conjunction with the Basis of Issue Plan Feeder Data, BOIPFD, described below) by the New Equipment Training section of the major subordinate command sponsoring the new system. The QQPRI provides information about the projected operator and maintainer positions, and it references each position to an Army standard task list such as AR 611-20. This information is contained in items 3, 4, and 5 of the QQPRI. A QQPRI for an electric power plant is provided in Appendix F. If there were new or unique tasks for electric power plant crews, they would be listed in Item 5.

The task listings for operator and maintainers are reviewed by the training developer at the proponent school. The training developer fills out the "Training Impact Worksheet" which includes revised task lists. (A Training Impact Worksheet is presented in Appendix G.) The new task listings are reviewed by the TRADOC integration centers and HQ TRADOC. The list of approved tasks for operators and maintainers forms the basis for the New Equipment Training Curriculum, described below.

Basis of Issue Plan (BOIP). The first estimate of required equipment capabilities is provided by the major support centers and reported on the BOIPFD. In Item 9 of the one-page BOIPFD form, the principle item is listed and supporting subsystems are listed with it. All BOIPFD forms are reviewed for accuracy and stored at the Equipment Authorization Review Activity in Woodbridge, Virginia. Once BOIPFD leave the major support command, they are collectively referred to as the BOIP. The BOIP is developed by the TRADOC proponent, using information from the BOIPFD, QQPRI, and New Equipment Training Plan. The Product 5 user can refer to iterations of the BOIP for changes made in the MOS assignments (Item 18), and then refer to an Army Standard task list such as AR 611-20 or updates to the QQPRI task lists. Appendix H contains a BOIP for a multipurpose bayonet.

TRADOC submits the BOIP containing justification for the items in the system and MOS assignments to HQDA, Deputy Chief of Staff for Operations and Plans (DCSOPS) for review and approval. The BOIP is revised as new information becomes available. DCSOPS is the central office of record for BOIPs. The central data base for BOIPs is kept at the Combined Arms Center Proponency Office, Fort Leavenworth, Kansas.

Input Data for Task Sequences

New Equipment Training Curriculum. This document presents the earliest task sequences. This curriculum is developed by the New Equipment Training Section of the major support command. This curriculum takes the task list from the QQPRI, and sequences the tasks. This document is part of the system design documents and is evaluated at Operational Testing I (OTI), between Milestones 1 and 2, which is pre-prototype. The Product 5 user will find this a useful source of task lists and sequences. The document undergoes iterations through the testing process.

User-Generated Sequences. The user will also have the option of developing a task sequence, in the event that available system design

documents do not include sequences. The system will prompt the user in the development of task sequences by asking questions like "what does the soldier do next?"

Input Data for Task Times

Existing Sources. Data for maintainer task times are generated only after prototype development, during the Validation and Verification phase. These maintainer task time data are stored at the major support commands. These data are part of the Integrated Logistics System, in a report called "Support Item Utilization Summary." Appendix I presents a sample of this document for the FAASV.

Data for operator task times are not maintained as systematically as the maintainer task times. This is because task times and workload determine maintainer manpower requirements, but operator manpower requirements are determined based on a force structure analysis. The Product 5 user would be able to obtain operator task times on a developing system, only if special studies (for example by the Human Engineering Laboratory or TRADOC Analysis Center in White Sands, New Mexico) had been conducted. However, these data are not provided in the normal course of Army documentation.

The Product 5 user may contact the contractor designer of the system for estimates about operator and maintainer task times. The Product 5 user will be advised that task times obtained from the contractor may represent ideal task times, not necessarily the actual task times for the system design.

Product 5 Task Times Data Base. Obtaining task times from existing sources will pose a problem for the Product 5 user. Therefore, Product 5 will provide a hard-wired data base of operator and maintainer task times for use as default values if none are available. These values will be developed by the Product 5 team without use of Army subject matter experts. The data base will contain task times of previous systems, obtained from TRADOC proponents and test data. Use of this data base will not require the Product 5 user to step through a lengthy analysis in order to determine a comparable system. The user will select task times from the data base matched at a gross task level.

Two approaches to the development of the task time data base have been considered, and one approach selected. One formal approach for determining task time data employs predetermined time systems. Predetermined time systems consist of elemental times associated with specific hand, arm, upper body, and body motions required in the accomplishment of well defined tasks. These times are independent of the particular application environment. The most widely used predetermined time system is the Methods Time Measurement (MTM) system. MTM consists of a series of tables containing the time required to accomplish various motions as a function of distance traveled, level of difficulty, weight of object moves if applicable, and degree of symmetry of motion. Additionally, a table indicating which motions are easily performance simultaneously is provided. Task times can be determined through MTM analysis by a properly trained analyst. This approach has been

rejected for use in establishing the Product 5 task time data base because it is too labor intensive.

The approach to be taken in developing the Product 5 task time data base is use of "standard time data." Standard data are task times at a higher level than that generated by predetermined time systems and are customized to a particular application environment. Standard data are maintained in a data base where they can be updated and used as appropriate. Standard data can be developed from predetermined time data, time observations, or estimates based on other weapon systems. The Product 5 team will develop the initial data base from task time data from other weapon systems. The advantage of standard data is that they can be continually refined, augmented, and maintained so that the time data base can be used for a variety of weapon systems. Over time, the Product 5 user may wish to update the task time data base with times from system analyses as they become available.

The standard task time data base for Product 5 will be designed and structured so that it interfaces directly with the Product 5 software. The data base will be designed as a direct access data base, structured similarly to the task templates used to cluster tasks by performance objectives. All data in the standard time data base will be coded to indicate the source of time data (e.g., previous weapon system, timed observation) so that the user knows the level of accuracy associated with the task time data. The user will always be given the opportunity to override the task time data drawn from the data base and provide a more acceptable task time. The user will also be guided to enter these new times into the task time data base, by providing the task, time, and data source, such as logistics documents, field testing, subject matter expert estimate. As Product 5 is used more and more, the standard task time data base will grow.

<u>Summary</u>

The Product 5 user must input new system performance objectives, task lists, task sequences, and task times. The Product will output manpower estimates using data of varying quality. Early in system design, input data will be sketchy and of a draft nature. As the development cycle progresses, more accurate system data will be available to the Product 5 user. Still later, the government and contractors will more rigorously analyze the design. Once a prototype is built, field study data are available. Finally, full scale development and deployment will provide actual system data.

Product 5 is designed to handle the sketchy data available early in system design as well as complete data sets available later. It provides a macro-structure for data inputs which allows users to maximize the data available. It allows user to enter system data from actual or imagined system designs. As for task times which are usually only available later in the development cycle, the Product provides time values which can be used as defaults. The quality of the manpower estimates generated by Product 5 will naturally improve with the quality of the input data. However, the Product

is intended to reach an acceptable level of output accuracy in time to significantly contribute to the prototype funding decision.

A system design is a collection of documents that undergo iterations as more is learned about Army requirements and system capabilities. Product 5 uses as input data important features of system design in order to generate the manpower requirements of the design. These manpower estimates derive from the system itself, not from its similarity to a previous system.

THE PROCESS OF PRODUCT 5

Product 5 will be capable of determining tasks and crew size associated with crew operator and maintainer jobs. Figure 2 earlier showed that two sequential analyses will accomplish this. The first of these analyses identifies the relationship among operator or maintainer tasks by clustering similar tasks. Once the tasks are clustered, the second analysis segments the aggregated tasks into work assignments (jobs) to determine crew size. This chapter is subdivided into two main sections to thoroughly describe these two analyses.

Analysis I: Task Clustering

In this section of the paper, the matter of rendering system-descriptive data from system design documents into a comprehensive system-to-task taxonomy is addressed. The purpose of this procedure is to consider all functions and corresponding performance objectives which the system must achieve, to consider all system tasks in relation to these, and objectively cluster the tasks into a taxonomy. The taxonomy will reveal the interrelation of the tasks, and thus all required operator and maintainer operations. Later analysis will partition the task clusters into jobs, and thus generate manning requirements (i.e., crew size, described in the section on determining unique jobs).

Overview of Task Clustering. The prior section of this paper focused on input data acquisition. This section elaborates in detail on the specific nature of the input data and its manipulation toward identifying operator and maintainer task clusters. A brief overview of the key elements of this methodology will be useful prior to detailed discussion. The key elements are:

- Inputs to Task Clustering:

  1. Performance objectives including criteria and conditions for each system function.

  2. Tasks associated with the system component(s) that support performance objectives.

  3. Measure of association between tasks and system performance objectives.

- Method of Task Clustering

  1. Use of performance conditions: Within a system mission, system functions and their corresponding performance objectives will have been identified from data sources described earlier. For each performance objective, the conditions under which performance occurs will vary (e.g., day vs. night operation) and may alter performance criteria. Thus, performance conditions for any one objective will be established as "cases" across which analysis occurs.

2. Use of tasks: System components (hardware/software) which support a function and its performance objectives will be identified from the system design data. Tasks required by these components will then be identified to serve as the "objects" of analysis.

3. The above input data will be keyed into the computer hosting the Product 5 tool. A user protocol will be developed (as part of a user guide) for the raw data; a menu-driven approach will be built into the program to aid input procedure and data editing.

4. Tasks will be classified by the user as to which system performance objective they support or belong to. If the performance objective could be expected to be performed under various field conditions, the performance objective will be represented several times in the matrix (for each condition) and the tasks classified on each. No subject-matter-experts will be needed to make the task classifications.

5. Hierarchical cluster analysis (or variant) will be applied to a "<u>task</u>" X "<u>performance objective</u>" data matrix to analyze the data and identify task clusters.

- Outputs and Use of Cluster Analysis

1. Hierarchical cluster tree (taxonomy) of system tasks will be derived to show the operational relationship of all tasks (both operator and maintainer) and relation of these to system mission, function, and associated performance objectives.

2. The next analysis performed by Product 5 (description to follow this one) will partition the derived task clusters into jobs/ personnel required to determine crew size.

<u>User Inputs to the Task Clustering Matrix</u>. The user makes three inputs to the task clustering matrix: rows of system performance objectives, columns of tasks, and a determination for matrix cells (only those that are not automatically entered by the system) indicating a positive relationship between a performance objective and tasks.

Prior to effecting the task clustering, three levels of information (mission, function, and task) will be available for input into the tool by the Product 5 user. The sources of these data were discussed earlier. Of these, only two inputs will be required for Analysis I (the cluster analysis): performance objectives and task list. These inputs serve as the "cases" and "objects" of analysis, respectively. Task clustering requires the creation of a "performance objectives" by "tasks" matrix.

As described earlier, the system will impose a macro-structure on data entry by using templates developed from the Kaplan and Crooks (1980) taxonomy. Use of the Kaplan and Crooks templates will assure that all

system performance objectives and tasks can be accounted for even in the early stage of system design.

The user will enter data into the matrix by entering one row (system performance objective) and its associated columns (tasks), then progress to the next row and its columns. The system will begin the data entry process by prompting the user to specify <u>system component mission</u>. The system will provide a data source for this item. If the user does not have the information, the system missions from the Kaplan and Crooks taxonomy will be presented, and the user will select one of those. An example of a system would be "aviation system," an example of a system component would be "pilot-operated defense system," and an example of a system component mission would be "destroy enemy vehicles."

Next, the system will prompt the user to enter the first <u>system performance objective</u>. As will be thoroughly described in the section on forming unique jobs, performance objectives refer to a time constraint, output requirement, or continuous activity. The user will be prompted to provide three pieces of information for each system performance objective: the goal, conditions of performance, and criterion of performance. An example of system performance objective goal would be "to defend the aviation system against enemy fire causing the enemy to retreat or be destroyed." An example of a performance condition would be "in the air, in the presence of an aggressing air vehicle, during the day." An example of a criterion of performance would be "enemy retreats or is destroyed without loss of life or property to our force." With data entered, the user stores (by pressing a function key) the system performance objective, named Objective 1.0 by the system or something more descriptive by the user. Any change in performance condition of performance criterion becomes part of another system performance condition.

The user will able to enter free text system performance objectives. However, invocation of the system "help" function will produce a menu of options for each part of the system performance objective. These options will be derived again from the Kaplan and Crooks taxonomy.

Once Objective 1.0 is stored, the user will be prompted to enter the <u>tasks</u> associated with accomplishment of that objective, and data sources will be provided. The user enters each task in free text. (The system will prompt the user to enter these tasks in sequence. Task times will be entered at this time as well if the user desires.) If the user does not have the information, the user can press a function key and produce menus based on the Kaplan and Crooks taxonomy from which to select tasks. When all tasks for the given objective are entered, the user presses a function key to save the data. Then the system prompts for the next system performance objective and its associated tasks.

With information on "tasks" and "performance objectives" entered, the two dimensions of the input data matrix will be established. Figure 6 shows the dimensions of the data matrix constructed at this point from input data. The relationship between the two dimensions for the data matrix shown in Figure 6 is logical. All parameters of the system are accounted for by the

System Function		Tasks for System Component(s): $SC^{(1)}$			$SC^{(2)}$				$SC^{(3)}$		
		$T_1^{(1)}$	$T_2^{(1)}$	$T_3^{(1)}$	$T_1^{(2)}$	$T_2^{(2)}$	$T_3^{(2)}$	$T_4^{(2)}$	$T_1^{(3)}$	$T_2^{(3)}$	$T_3^{(3)}$
	$C_1^{(1)}$	0	1	1	0	0	0	0	0	1	1
$PO^{(1)}$	$C_2^{(1)}$	0	1	1	0	0	0	0	0	1	1
	$C_3^{(1)}$	1	1	1	0	0	0	0	1	1	1
	$C_4^{(1)}$	1	1	1	0	0	0	0	1	1	1
	$C_1^{(2)}$	0	0	0	1	1	0	0	0	0	0
$PO^{(2)}$	$C_2^{(2)}$	0	0	0	1	1	1	1	0	0	0
	$C_3^{(2)}$	0	0	0	1	1	1	1	0	0	0
	$C_1^{(3)}$	0	0	0	1	1	1	1	0	0	0
$PO^{(3)}$	$C_2^{(3)}$	0	0	0	1	1	0	0	0	0	0
	$C_3^{(3)}$	0	0	0	1	1	0	0	0	0	0

KEY: SC = System Component (i.e., hardware/software) associated with system function.
T = Task associated with a system component (e.g., a task could be load, aim, or fire weapon).
PO = Performance Objective that supports a system function.
C = Relevant Condition under which performance occurs, e.g., day, night, target moving, target stationary.
0 = Task does not pertain to the PO.
1 = Task pertains to the PO.

Figure 6. Matrix for Creating Task Clusters.

dimensions. If the system is large, the user will enter performance objectives for one component, then move to another component.

Entering data into the cells is the next step. It must be determined which of all the tasks listed in the matrix columns relate to each system performance objective. Simply, the tasks will be classified as to which performance objective the tasks apply (a matter already known from the initial system design inputs). Dichotomous scoring (i.e., 1 = if pertaining to the performance objective, 0 = if not) will be used to classify each task and thus provide all tasks with a cell entry. The cells will be filled in one of two ways. First, the system will automatically enter a "1" for each task that was entered following the entry of a performance objective. Second, for those cells not filled automatically, the user will be taken to each cell and asked to determine task-system performance objective relationships. Once the cells of the matrix are filled, hierarchical clustering of the matrix can be accomplished to define task interrelationships.

Figure 6 provides example cell entries. These have been prepared to illustrate task clustering for two possible types of clusters. Tasks under system component (SC) #1 (say a mounted weapon) fulfill performance objective (PO) #1 and its four variations (performance conditions). Tasks under SC #2 serve PO #2. Obviously, these two distinct sets of tasks bear little relation to one another and will emerge in different clusters. On the other hand, tasks under SC #3 are identical to those of SC #1 and likewise serve PO #1. Why? Presumably, it is a second mounted weapon located apart from SC #1 and suggests that a second weapon operator will be required. The point to be made is that such a duplication will not be lost in the data matrix nor in the output -- two mounted weapon operations will emerge in a single cluster while the tasks associated with SC #2 will, as stated before, emerge as its own separate cluster.

At this point in the process, the user can obtain a printout of the matrix to review. Revisions to the matrix can thus be made before the cluster analysis process is undertaken by the system.

<u>The Cluster Analysis Process</u>. Hierarchical cluster analysis is the analytic design of choice for rendering the "<u>tasks</u>" X "<u>performance objectives</u>" matrix into a taxonomy of task relationships (task analysis). There are a number of reasons for selecting clustering, and this particular design, for the present analysis. Though hierarchical clustering is perhaps the best known and more used method of late, there are many approaches to clustering. Some employ conventional clustering procedures; others rely upon factor analytic techniques (Guertin, 1971). Still others, such as the SAS "VARCLUS" method combine elements of both cluster and factor. Some excellent reviews of the range of methods are found in Lorr (1983) and Thorndike (1978).

One important difference between cluster and factor methods is that in cluster methods a variable is assigned to only one cluster -- whereas factor analysis breaks up the variance of a variable into several additive parts. Thus, cluster is the design of choice when one wishes to build something up from individual elements (synthesis) as is the case where tasks must be

aggregated into related of activities for operators and maintainers. The critical statistic employed to effect the design is Euclidean distance between the variables (tasks). Essentially, the mean distance among variables within a cluster is compared to the mean distance between all variables in the analysis as variables are successively compared to leading and later clusters for membership. The output is a hierarchical cluster tree and metrics of association among variables; numerous other supplemental statistics are also provided.

For the proposed analysis, the tree would reflect all tasks ordered into operations (i.e., their functional relationships) amenable to later subdivision into work stations (jobs) and, thus, crew size. An illustration of the prospective result is shown in Figure 7, although this type output from Product 5 will be much more easy to read than the sample. To effect the cluster analysis, which tasks to enter into the analysis at any one time must be a consideration. The system of interest may simply be too large (too may tasks) to conduct an analysis which involves all system operations. Further, the user may not have all system data available; the data will likely evolve in "chunks" and part-system analysis may be of interest. The solution is to select system components as the basis for which tasks are included in analysis. In other words, the user will conduct multiple analyses of the system -- component by component. Results of the component analyses can be integrated for the total system through second order clustering to join components.

Clustering Problems. Historically, two problems have stirred controversy as regards the use of cluster analysis. The first concerns the selection of algorithms for joining clusters. In recent times, clustering has become more accepted, and this concern has lessened due to the proven robustness of cluster solutions and widespread acceptance of mediating algorithms such as those by Hartigan (1975) and Johnson (1967) which are in use with notable statistical packages such as SAS and BMD. Additionally, selection of a distance algorithm is trivial in the present case due to the intentional use of "1" and "0" as the coding scheme, which reduces all distance measures to a singular and highly reliable range (unitary measure). The effectiveness of this approach has been demonstrated in a similar context by Kraemer, Boldovici, and Boycan (1975) and Wheaton, Fingerman, and Boycan (1978). The latter study produced a clustering algorithm for the Army Research Institute. The algorithm is in the spirit of Hartigan's approach and delineates the steps through which clustering. A copy is provided in Appendix J. The clustering algorithm for the present concept is expected to be similar. It will be beneficial to ARI to possess its own variation on this model and thus be free of use constraints imposed by proprietary software.

The second problem concerns criteria for optimal clusters -- a problem shared by factor analysts when attempting to determine the minimal number of factors that will optimize the accounting of variance in a factor solution. In-depth discussion of this problem and its solutions can be found in reviews of clustering techniques by Anderberg (1973), Everitt (1947) and Friedman and Rubin (1967). Unfortunately, cluster analysis is a poor cousin to factor analysis regarding availability of optimal-cluster estimation methods. However, Kendall (1980) points out that cluster solutions fall

All System Tasks are Clustered Functionally to Define O&M Activities:

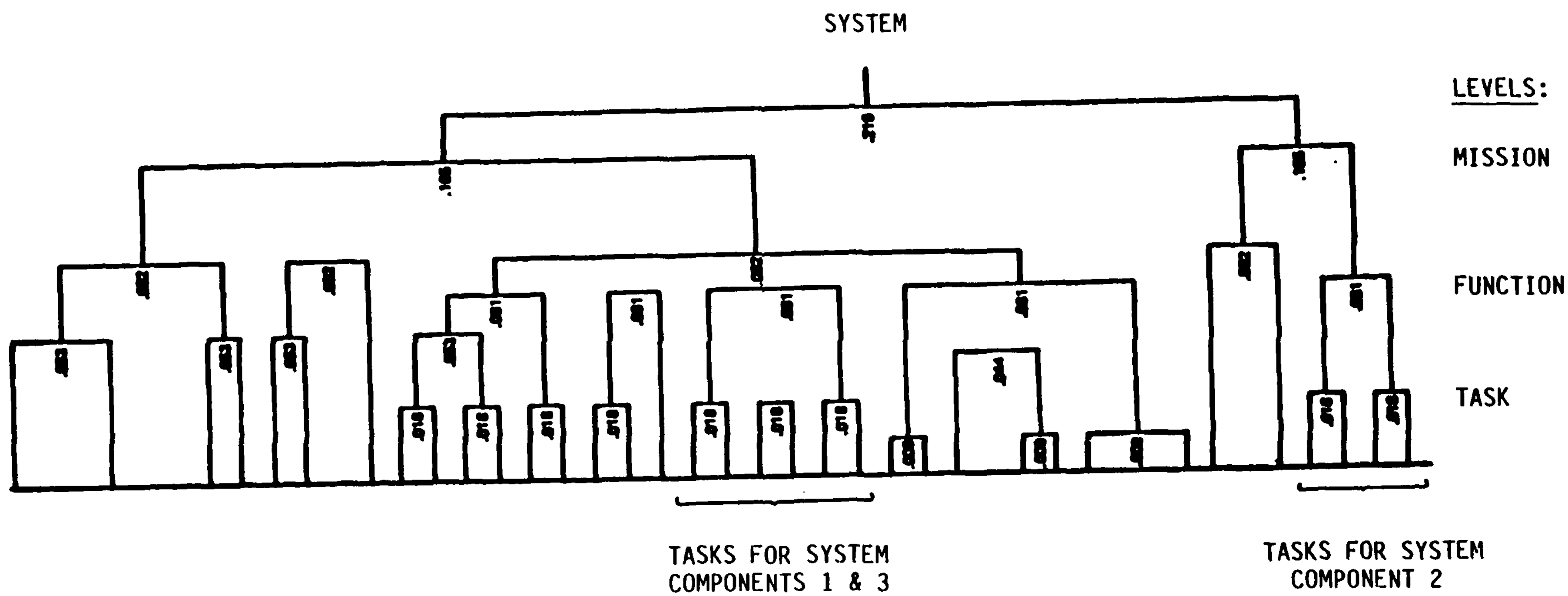


Figure 7. Example Cluster Analysis Results (for system shown in Figure 6).

into two categories: those where clusters are correlated and those where they are not. In the former case (correlated, as it is expected that many of the system tasks will be), Kendall demonstrates that the number of clusters should be equal to the number of factors derived for the same data set in a factor analysis. Fortunately, factor estimation criteria (while not perfect) are richer in number and mathematical soundness than those for selecting optimal number of clusters (e.g., Cattell's scree test, the Joreskog model, Kaiser's default criterion, Fisher's test for the significance of factors; see Child, 1970, Kendall, 1980, and Joreskog, 1971). A number of these are in wide use with major statistical packages, and all can be programmed for automated determination. As it seems infeasible that for a single system or system component all tasks would be discretely independent (no inter-correlation), then one or more of the factor criteria for selecting the optimal number of clusters could be incorporated into the PC-AT program.

PC-Based Clustering. A final consideration is how to effect the hierarchical clustering routine on a stand-alone PC-AT type computer? The major limitation here is random access memory (RAM) limitations assumed by commercially available cluster routines for PCs. (For example, one of the better programs available from Spring-Stat Statistics restricts the PC cluster program to a 20 x 40 matrix.) Given this commonplace inavailability of programs to do the job, it is assumed that a tailor made software program must be developed for this product.

Even with a uniquely designed program and a gigabyte or extended memory, the PC might still experience memory (workspace) limitations that preclude analyzing all components of a complex system design at once. Cluster analysis will have to address one or a few components of the subject system at a time. How, then, will these be merged together to achieve a total system analysis. Just as a factor intercorrelation matrix can be second and third order factored and so on to reveal a hierarchy of constructs underlying a set of related factors, so can the cluster analyses of individual system components be later joined into a comprehensive scheme. For example, the outcome of the example data matrix given in Figure 6 is shown above a bracket in Figure 7. The use of intercluster association metrics permits the smaller solution to be merged with other small solutions into a whole via higher order clustering of the metrics. This procedure can be programmed into the PC clustering routine.

Output of Clustering. The terminal output of the system-task taxonomy analysis was illustrated in Figure 7. There, all system missions, functions, and tasks associated with system components and performance objectives are accounted for in terms of operations or maintenance clusters. The figure obviously illustrates an entire system accounting. For a very small system this may be possible as a single analysis on the PC-AT. More likely, though, the process will be iterative -- accounting for the system by analyzing only one or a few components at a time, filing that result, and continuing until all components have finally been accounted for.

Cluster analysis output represents a significant step forward toward achieving the goal of Product 5. Early source data were transformed objectively to a more manageable and reliable data set for further

manipulation. The output data set will include not only the hierarchical cluster tree, but also strength-of-association metrics and numerous optional statistics such as scale scores. (The printout will be designed for ease of use, and it will not intimidate the non-statistician.) The present output reports the functional interrelationship of all system tasks and can now be reduced to prospective operator or maintainer job assignments (estimation of crew size). This can be accomplished in either the predictive mode (determine minimal, adequate crew given the system design) or in the prescriptive mode (validate, from system characteristics, a predetermined crew size).

The next section describes the techniques to be employed to derive operator and maintainer jobs from the objectively clustered tasks.

Analysis II: Converting Task Clusters Into Unique Jobs

General. The number of jobs required to operate and maintain a weapon system depends largely on the functions that must be performed and the sequence and timing of the requirement for these functions. The previous section described the methods for clustering tasks into clusters such that the tasks within a cluster relate to similar performance objectives. In this section, an approach for partitioning the tasks within each cluster into specific jobs is described. Consistent with the clustering step, the approach for partitioning clusters into jobs is amenable to automation in a microcomputer environment. Both operator and maintainer jobs are considered. Three inputs are required: (1) The functionally aggregated tasks output from Analysis I, (2) task sequence, and (3) task times (see Figure 2). These data and their entry were previously described.

Categories of Task Clusters. The operator and maintainer task clusters will be classified into one of three categories based on the nature of the performance objective with which they are associated. Although tasks in different clusters may be similar in nature, jobs created from the different clusters will differ substantially in terms of how the jobs are derived. These task cluster categories are defined as follows:

- Category 1: Time-based, mission-oriented operator/field personnel tasks. Category 1 tasks are those that must be completed within a specified time period, i.e., a response time. These tasks are associated with performance objectives that include mission timelines. While the tasks in this category are not performed constantly, they must be performed within a specified amount of time once a order to begin is received. The response time requirement is relatively independent of the number of times the task must be performed. Examples of such tasks include the tasks required to execute a fire mission aboard a self-propelled howitzer or the time within which a repair team effect a specific field repair task. These tasks tend to be mission-oriented operator tasks or task executed by personnel in the field.

- Category 2: Output-based, maintainer tasks. The second task category consists of those tasks that are performed continuously

over time and result in the production of some countable output (e.g., parts replaced or repaired). The performance objective for these tasks may include some production level requirement. Tasks in this category are more easily anticipated and, therefore, the workload can be arranged such that a relatively constant flow of work is maintained and the workload can be balanced among the jobs. These are most likely to be maintainer tasks that take place at the intermediate or lower levels.

- Category 3: Cognitive/monitoring tasks. The third category of tasks includes those tasks that are performed constantly and not measured in terms of number of units of output produced (e.g., fire missions, rounds of ammunition, remove and replace actions) but rather in terms of the period of time during which the task must be performed. The performance objectives associated with these tasks are more likely to be cognitive in nature. Examples include surveillance or security activities and equipment or situation monitoring. These are operator tasks.

The nature of tasks in each of the categories dictates that they be treated differently when determining the number of jobs required to perform the tasks in a manner that meets mission and support requirements. Note that while accuracy requirements must clearly be associated with the performance objectives of tasks in all three categories, the way jobs are created is largely determined by how much time is available for accomplishing each task. In Category 1, jobs must be assigned such that response times are met with secondary consideration given to how well balanced the tasks are among the crew. Tasks in Category 2 should be assigned to jobs such that the workload is reasonably balanced while meeting the "production" requirement. Note that while tasks may be assigned to jobs in a number of ways in order to meet the production requirement, the purpose for balancing the workload among jobs is to minimize the variance in idle time among the jobs so that the work can be performed as efficiently as possible. Category 3 tasks generally dictate the number of jobs required based on their location and/or area of responsibility rather than on the time required to perform specific tasks. Consequently, the approach to assigning these tasks to jobs is much simpler than that required for tasks in the first two categories.

The tasks in each task cluster will be partitioned into unique jobs using generally accepted industrial engineering and operations research techniques for structuring, measuring, and organizing work. The method used to determine jobs using tasks in Categories 1 and 2 described above employs "network analysis" techniques. The tasks in Category 3 are overlaid onto jobs in the first and second category subject to limitations due to proximity and available time. Figure 8 shows graphically the process to be used for converting the tasks in each cluster into unique jobs. A more detailed graphic will be presented for each task category, later in this section.

Forming Jobs From Category 1 Tasks. The process for forming jobs from Category 1 task clusters is drawn largely from the production scheduling and

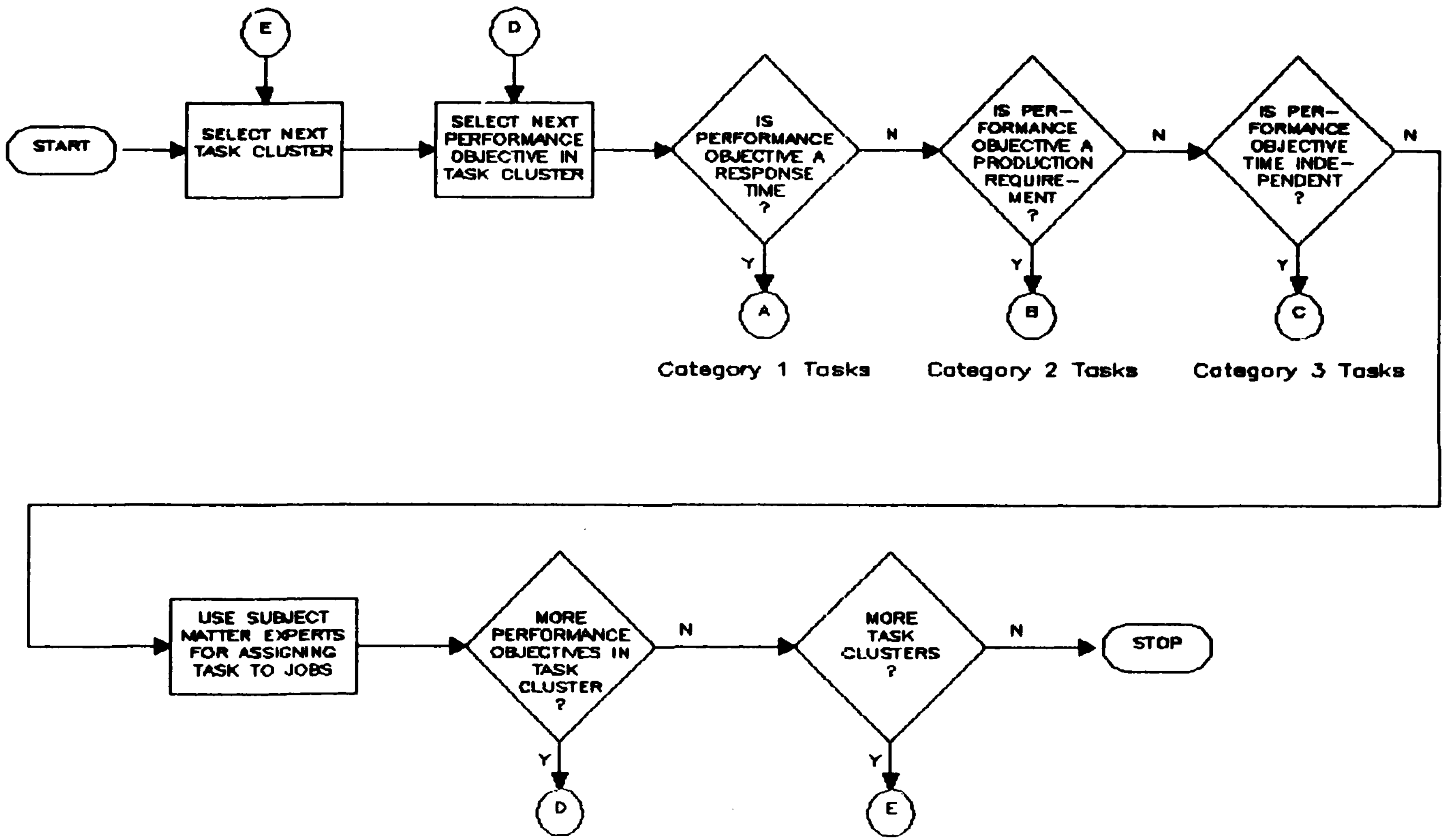


Figure 8. Process for Converting Task Clusters Into Jobs.

resource planning literature. Figure 9 shows the process of creating these jobs. The steps are listed below.

1. Determine the technological sequence of tasks required to perform each function. (User may update original entered sequence.)

2. Develop a precedence network defining the task relationships to the required functions.

3. Determine the time required to perform each task under each set of environmental conditions. (Input earlier, user may update.)

4. Identify required response time for the job function and check task times against response time requirement. If one or more task times exceed the response time, the task(s) must be redesigned or the response time must be relaxed.

5. Identify constraints on assigning tasks to jobs due to proximity and simultaneity requirements.

6. Using automated resource allocation techniques, create work stations/jobs based on the precedence network and response time requirements.

7. Test the sensitivity of the number of work stations/jobs to the response time requirement.

8. List the possible job assignments and resulting response times.

Input to Step 1 is the task sequence entered by the user during data entry. Each task related to a given system function is entered by the user along with its immediate predecessor(s) (i.e., the task(s) that must be completed before it can begin). Note that all tasks related to a given function will fall in the same task cluster since clusters are formed on the basis of performance objectives. The system design will drive the task sequence. The sequence will be determined by successively asking the question "What tasks must be completed before this task can begin?" The questioning process continues until all tasks related to a function have been placed in sequence (note that some tasks or series of tasks may be performed in parallel).

Step 2 formalizes the information collected in the first step by creating a network that reflects the aggregate set of precedence requirements associated with the successful accomplishment of a given function. The precedence network is important in that it identifies those tasks that must be performed in sequence and those that can (but not must) be done at the same time. This is done automatically.

Step 3 assigns times to each of the tasks in the precedence network. The method that Product 5 will use to identify and assign task times was discussed earlier. An example of a precedence network (from Step 2) with task times (from Step 3) is shown in Figure 10.

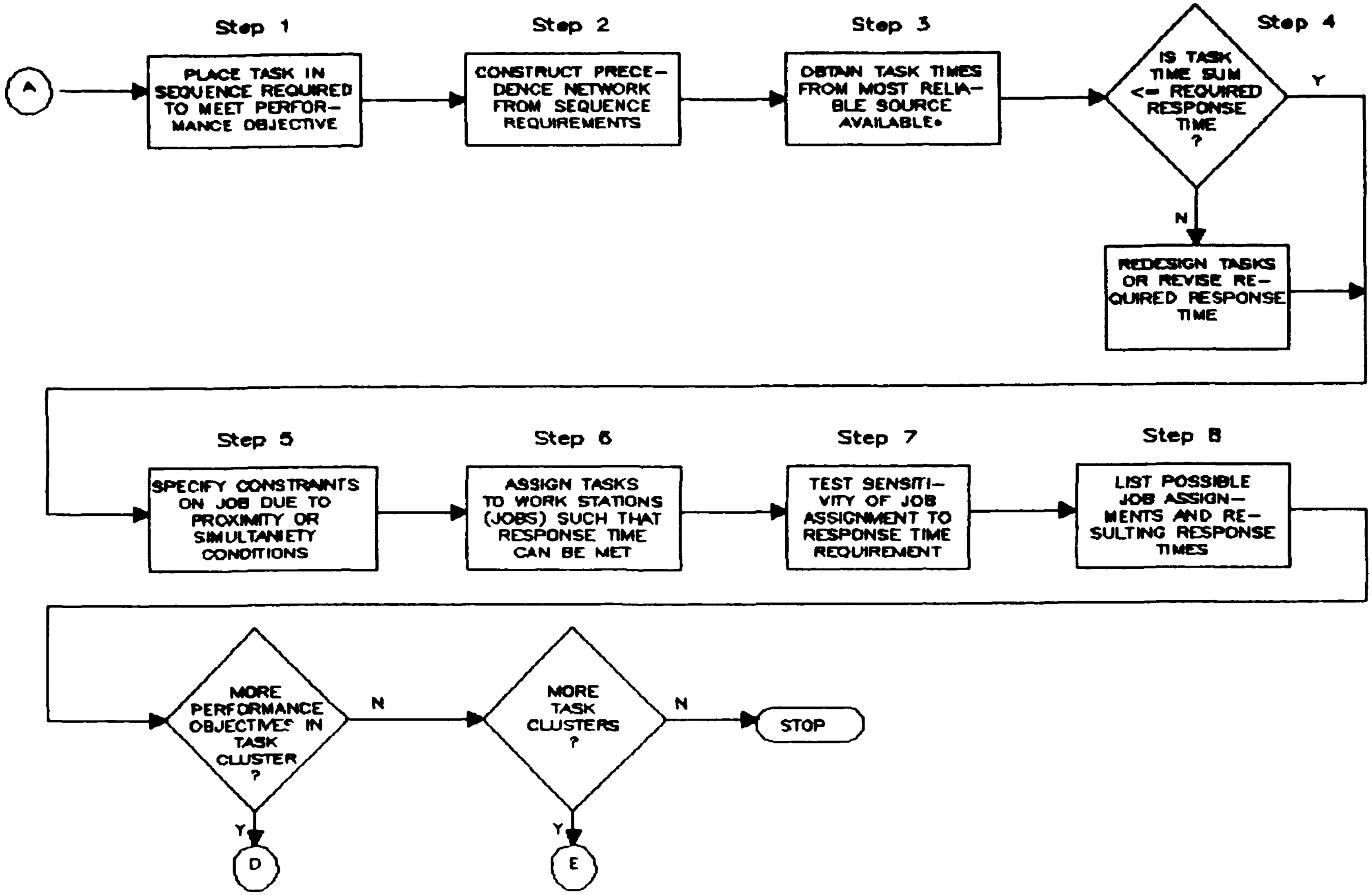


Figure 9. Process for Converting Category 1 Task Clusters Into Jobs.

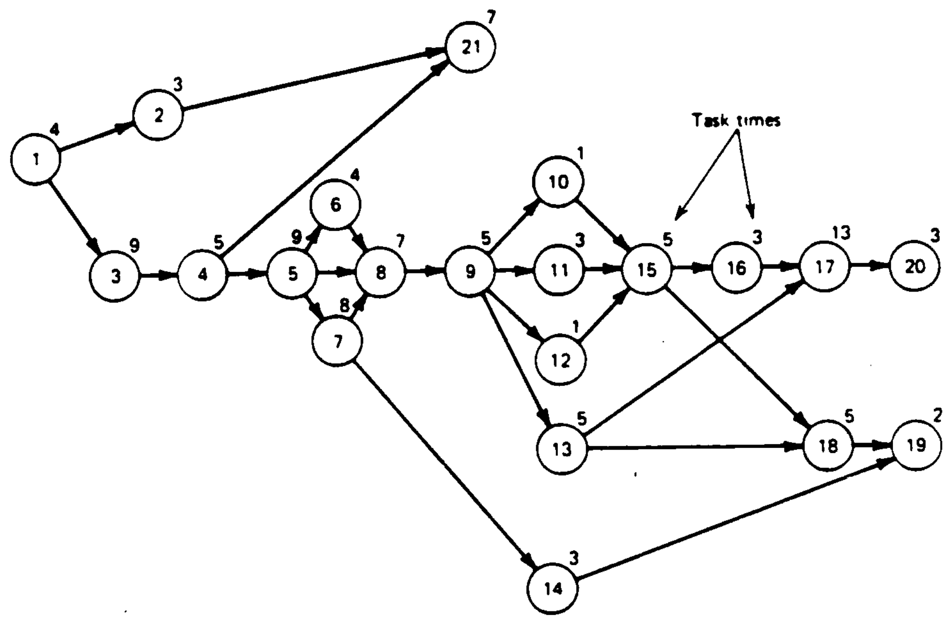


Figure 10. Category 1 tasks arranged in a precedence network based on sequence and time requirements (from Bedworth and Bailey, 1982).

In Step 4, the response time requirement for the total job function is identified for the specific set of tasks required to accomplish the function. Note that the achievable response time for a function cannot be less than the greatest sum of all sets of required tasks that must be performed sequentially. If the sum of the task times for a required set of sequential tasks exceeds the required response time, then the response time cannot be achieved regardless of the crew size. In this case, either the response time must be relaxed or the system must be redesigned to reduce the time required to perform the tasks in the sequence.

Step 5 in the job forming process requires identification of any constraints that might affect the partitioning of tasks into jobs. These constraints will restrict the formation of jobs and may arise due spatial considerations (i.e., distance between working areas in which tasks are performed) or a requirement that two or more tasks occur simultaneously or in rapid succession. Tasks that cannot be combined into the same job will be tagged to ensure that they are not combined. Another form of constraint is one that requires a set of tasks to be performed by the same person. Constraints of this type may cause tasks from different job clusters to be combined in the same job. The user will be asked if simultaneity or proximity constrains job function. The system default will be "no" constraints.

Step 6 of the process is at the heart of the job forming process. The process makes use of a network analysis technique know as the critical path method (CPM) or critical path scheduling (CPS). In the case of Category 1 tasks, the objective is to determine the number of jobs required to meet the mission timeline requirements for completing all the tasks required to successfully accomplish the function.

Step 6 is an iterative process through which tasks are assigned to a given crew size such that the response time is minimized. If the minimum response time achievable with a given crew size is unacceptable (i.e., it fails to meet the system requirement), the crew size will be increased. This process will continue until the point where either the requirement is met or further increases in crew size do not decrease the response time. This process is repeated for each job cluster containing Category 1 tasks. In each case, the minimum number of jobs that can still meet the required response times is determined. The largest of these minimum requirements is the lower bound for jobs for the weapon system for Category 1 tasks. If any of the functions must be carried out simultaneously, the number of jobs must increase to permit all of the required tasks to be completed within the required time for all functions that must be completed together.

Several slightly different algorithms are available for implementing the resource allocation process described above. Lang (1977) provides a heuristic approach for allocating a single type of resource to tasks in a critical path network. An algorithm for allocating multiple resources was developed by Brooks (1963) and further extended by Bedworth (1973) and Bedworth and Bailey (1982). Bedworth and Bailey (1982) provided a computer coded algorithm that implements the Brook's algorithm.

Brook's (1963) algorithm (BAG) was selected for use in Product 5 for assigning Category 1 tasks to jobs. The computer coded algorithm is available for use in Product 5. The steps required to assign tasks (activities) to jobs (resources) are as follows. For convenience, Figure 11 gives a network and tabular results of these steps based on three jobs.

A. Develop the task network, identifying tasks and their required times.

B. Determine the maximum time each task controls through the network on any one path. This is like calculating the critical-path time through the network assuming that the starting node for each task being analyzed is the network starting node. This activity control time will be designated ACTIM for convenience.

C. Rank these times in decreasing ACTIM sequence, as in Figure 11 (G, A, C, etc.). ACTIM for task A is found by summing the times for tasks A, D, and E, to obtain a total of 16. The rows titled TEARL, TSTART, TFIN, and TNOW are explained as follows:

   1. TEARL is the earliest possible time, because of precedence and time limitations, to schedule each task. The actual time will be equal to or later than TEARL. TEARL equals the latest TFIN time for all immediate predecessor tasks.

   2. TSTART is the actual start time of the task. If there were no job limitations, TSTART would always equal TEARL.

   3. TFIN is the completion time of each task. This equals the tasks TSTART added to the job-duration time.

   4. TNOW is the time at which job assignments are now being considered. Initially TNOW equals zero, but subsequently it equals the lowest TFIN time for all tasks currently being worked on.

D. Sequence the tasks according to job constraints. TNOW is set at zero. The allowable tasks (ACT. ALLOW.) to be considered for scheduling at TNOW of zero are those tasks that would have a critical path method starting time of 0, namely tasks G, A, and C. These are placed in the ACT. ALLOW. row, sequenced in decreasing ACTIM order. In this example, G, A, and C all have the same ACTIM, and so a secondary rule is needed. For this example we will choose longest duration first, which dictates schedule G first. Another rule is needed for A and C, since both are five time-units long. Arbitrarily choose A before C. In the job-available column, the jobs initially available are placed--namely, three.

E. Determine if the first task in ACT. ALLOW., G, can be assigned. It can, since three jobs are available and G requires only one. Also, no predecessor limitations prevent G from beginning. G is removed from the ACT. ALLOW. list and the number of jobs available is decreased by one to a value of two, since G required one job.

STEP A: Develop Task Network

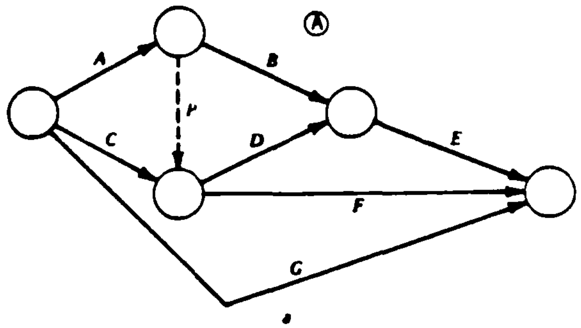
STEP B: Determine Task Duration

STEP C: Rank Tasks in Order of Network Durations (ACTIM)

STEP D: Determine Job Resources Available (3)

STEP E,F: Assign Tasks to Jobs, One Task at a Time in Network Order

STEP G: Repeat Process Until Jobs are Formed



B

Activity	Duration	Resources Required
A	5	1
B	4	1
C	5	1
D	7	1
E	4	1
F	8	1
G	16	1
P	Pseudo	—

	Activity	G	A	C	D	B	F	E	
ACTIVITY DATA	Duration	16	5	5	7	4	8	4	PROJECT COMPLETION TIME
	ACTIM C	16	16	16	11	8	8	4	
	Resources required	1	1	1	1	1	1	1	
	TEARL	0	0	0	5	5	5	12	
	TSTART	0	0	0	5	5	9	12	
	TFIN	16	5	5	12	9	17	16	

			Iteration 1	Iteration 2	Iteration 3	Iteration 4	
ALGORITHM ITERATION RESULTS	TNOW		0	F 5	9	12	G
	Resources available	D	3 2 1 0	2 1 0	1 0	1 0	
	ACT ALLOW	E	G A C	D B F	F	E	
	Iteration No.		1	2	3	4	

Figure 11. Brooks Algorithm Applied to Allocation of Category 1 Tasks to Multiple Jobs.

TSTART for task G is set at the current TNOW and the TFIN is set a TSTART plus task G's duration time. Now it is necessary to determine if task G being completed will allow another task to be feasible at some future time. With G it is not, since G is itself an entire critical path. This same process is repeated for the remainder of ACT. ALLOW. tasks until the jobs available are depleted. In this case, all task G, A, and C could be assigned a TSTART of zero. From the network of Figure 11 it is seen that assigning task A allows task B to be scheduled a TEARL of five time-units later (task A's TFIN). Similarly, tasks D and F can be assigned a TEARL that is the latest of A's and C's TFIN times. Note that if task A had required too many resources to allow assignment at TNOW of zero, we would still see if task C could be assigned.

F. TNOW is raised to the next TFIN time, which happens to be five, the completion times of both tasks A and C. The jobs available at TNOW of five is set to the number remaining after assigning resources at TNOW equal to zero (zero in this case), added to the number of jobs freed because of task co»pletion at the new TNOW (two in this case). ACT. ALLOW. we now set at those not assigned at the previous TNOW (none in this case), added to those that have a TEARL equal to or less than TNOW (D, B, and F).

G. Repeat this assignment process until all tasks have been scheduled. The latest TFIN gives the response time that can be achieved with the resources assigned--in this case, 17 time units. Three jobs have been scheduled.

Step 7 in the job forming process provides a means for investigating alternative numbers of jobs and assessing the effect of these alternatives on the ability of the system to meet performance requirements. For example, a slight relaxation in the performance requirement might result in a need for one less job. Conversely, by adding another job to a weapon system, system performance may increase dramatically. Systems designers and Army decision makers need to be aware of such swings in both requirements and performance in order to make rational design decision.

The product of this process will be a listing of the unique jobs that result from Category 1 tasks. With each job will be a listing of the specific tasks associated with the job. Also, for each function consisting of Category 1 tasks, a resource profile will be shown that indicates what each job is required to do, over what time period, and the proportion of the soldier's time that is spent doing the tasks assigned to the job.

Forming Jobs From Category 2 Tasks. Category 2 tasks are similar in many respects to Category 1 tasks except the time requirement is based on a production output requirement rather than a response time requirement. The process for forming jobs from Category 2 tasks is illustrated in Figure 12. The steps are listed below:

Step 1. (Same as for Category 1). Place tasks in sequence.

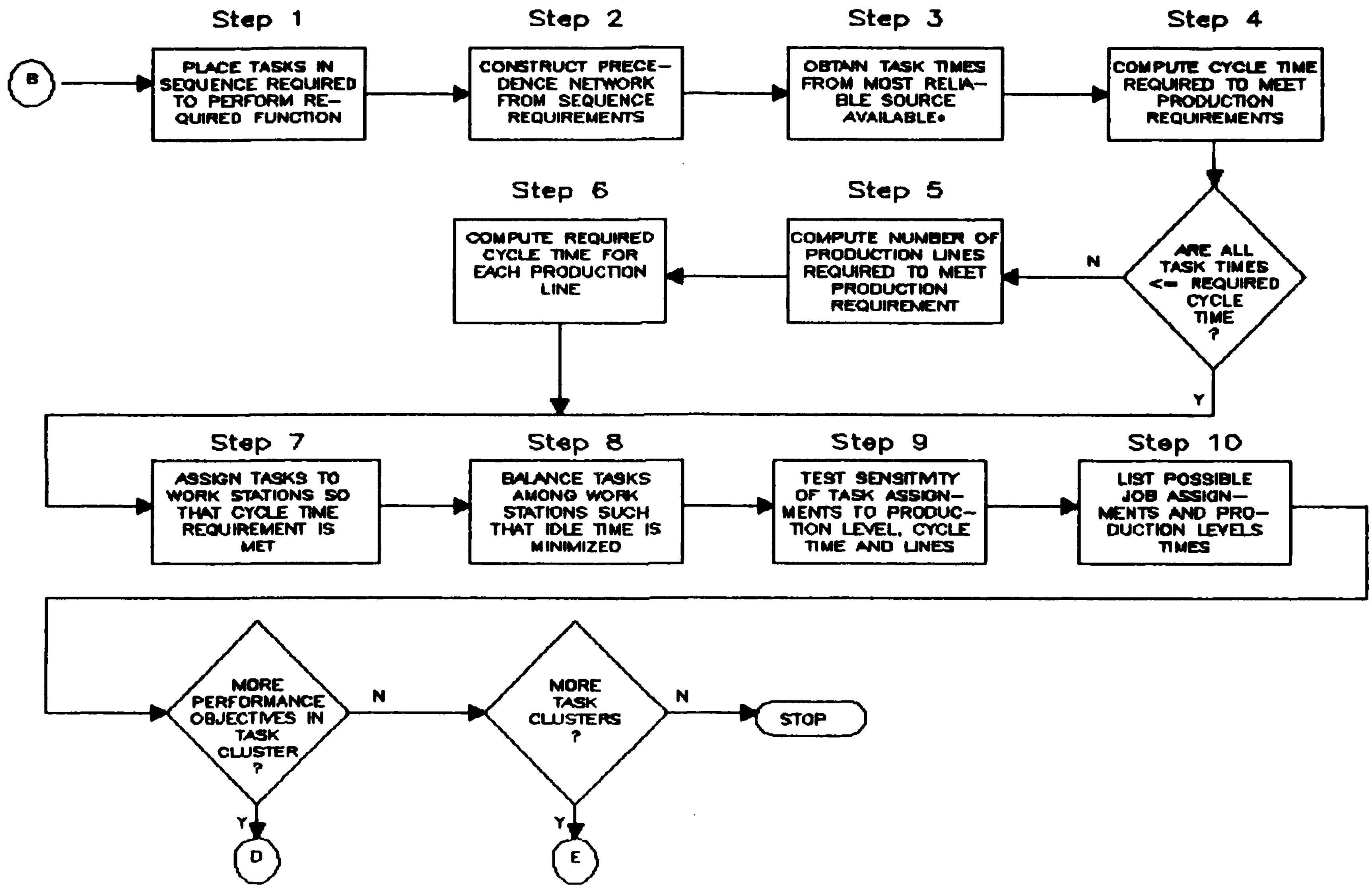


Figure 12. Process for Converting Category 2 Tasks Clusters Into Jobs.

Step 2. (Same as for Category 1). Construct precedence network based on sequence requirements.

Step 3. (Same as for Category 1). Determine task times.

Step 4. Compute cycle time.

Step 5. Compute number of required production lines.

Step 6. Compute cycle time for each production line.

Step 7. Assign tasks to work stations.

Step 8. Balance tasks among work stations.

Step 9. (Same as Category 1). Test sensitivity of work stations.

Step 10. (Same as Category 1). List jobs and task.

For Category 1 tasks, the objective was to determine the minimum number of jobs necessary to meet the response time requirements. Minimizing the number of jobs is also an objective for Category 2 tasks. However, the nature of Category 2 tasks is substantially different from that of Category 1 tasks. Category 2 tasks are most likely to be found in support areas where work can be more easily planned, scheluled, and controlled. For example, tasks that occur in a maintenance depot are more easily planned than those that occur in a field setting. Workload can be maintained at a more constant level with less need to respond quickly. Consequently, the objective in this environment, in addition to minimizing the number of jobs, is to assign tasks to jobs in a manner than balances the workload among the various jobs.

The approach used to create jobs from tasks in job clusters containing Category 2 tasks is similar to that used for Category 1 tasks. Steps 1 through 3 are exactly the same as that used for Category 1 tasks. Step 4 is where the production requirement is converted into a required cycle time. In Step 5, the production requirement will be expressed in units of work per time period (e.g., assemblies overhauled per year). Step 6 computes cycle time. Cycle time required to achieve the production requirement depends on the available time (e.g., one shift five days per week, 24-hours per day every day) and the number of "lines" performing the tasks. (A "line" consists of all jobs necessary to perform tasks related to a given function).

The production requirement can be achieved either by configuring the jobs such that the cycle time is sufficiently short to meet the requirement or by staffing several lines with jobs configured such that a somewhat longer cycle time is achieved on each line but the combine production rate of all lines meets the production requirement. The number of lines may be provided as a user input or can be computed from the production requirement and task times. Product 5 will be designed to accommodate either approach. For example, if four production lines are to produce, inspect, service or repair assemblies at a rate of 1000 per year and the repair facility is

scheduled to operate 40 hours per week, each line must achieve a cycle time of approximately eight hours (i.e., an assembly must come off each line at a rate of one every eight hours). If we assume the sum of times for all tasks required on each line is 30 hours and that no tasks exceeds eight hours, then at least 4 work stations (i.e., jobs) are required on each line. However, the actual number of jobs per line may exceed this limit due to precedence requirements or other constraints. The objectives in partitioning tasks into jobs is to assign tasks to jobs such that the production requirement is met, the number of jobs is at the minimum necessary, and the workload is reasonably well balanced among the jobs. The latter two objectives are complementary in that as the jobs become more balanced, the number of jobs required is reduced.

The procedure for allocating Category 2 tasks to jobs is equivalent to line balancing procedures used in a manufacturing environment. A number of automated approaches for line balancing are available that can be used in either of two ways. First, given the number of jobs or work stations, the algorithms assign tasks to jobs such that the production rate is maximized (or the cycle time is minimized). Second, given a required cycle time, tasks are assigned to jobs such that the number of jobs is minimized and the workload is as well-balanced as possible. Buffa and Taubert (1972) reviewed alternative means for achieving a well-balance assignment of tasks to jobs. One of the earliest proposed techniques for balancing workload is that developed by Helgeson and Birnie (1961). Further improvements in the workload balancing process were developed by Mansoor (1964), Kilbridge and Wester (1961), and Bedworth and Bailey (1982). The Bedworth and Bailey algorithm is available in code and will be used in the product.

Steps 5 and 6 of the process for assigning Category 2 tasks to jobs are similar to the allocation process used for Category 1 tasks. Alternate cycle times will be evaluated to determine their effect on the number of jobs required and the degree to which workload can be balanced among the jobs. The process can be described in the following steps:

A. Develop the precedence network in the same manner as for Category 1 tasks.

B. Assign precedence regions from left to right. Redraw the network, assigning all tasks the latest precedence region possible; this will ensure that tasks with few dependencies will at least be considered for assignment late in the schedule. Figure 13 illustrates how precedence regions are formed.

C. Within each precedence region rank tasks from maximum to minimum duration times. This will ensure that the largest task will be considered first, giving the chance for a better combination of smaller tasks later. Assigning most of the small tasks early is one problem with some solution techniques.

D. Assign tasks by the following sequence, conformirg to process zone restrictions. Results of task assignment are shown in Table 1.

   1. Leftmost region first.

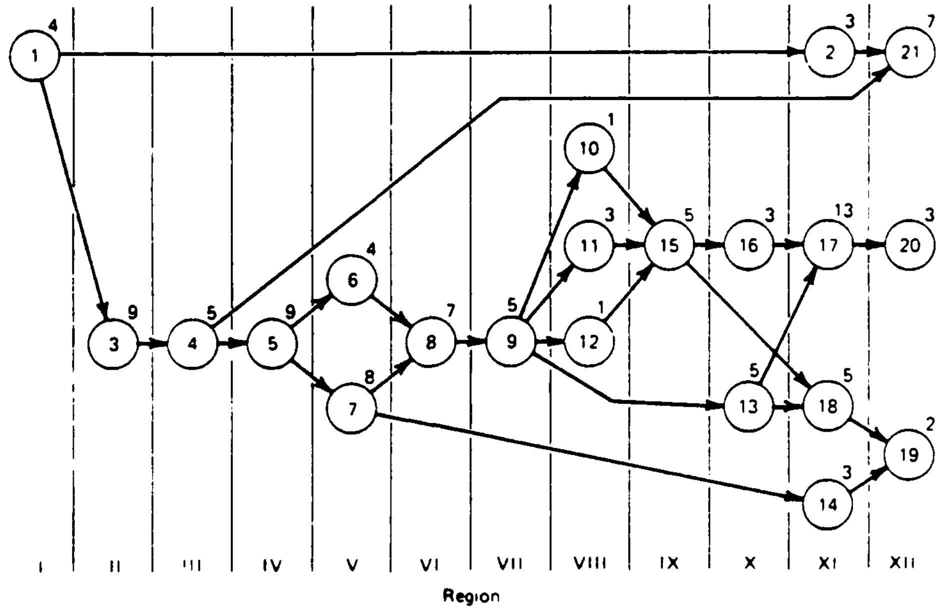


Figure 13. Precedence Network for Category 2 Tasks (from Bedworth and Bailey, 1982).

Table 1

Category 2 Task Assignments to Precedence Regions (from Bedworth and Bailey, 1982)

Region	Tasks (Within Regions, Priority Is Left-to-Right)
I	1
II	3
III	4
IV	5
V	7, 6
VI	8
VII	9
VIII	11, 10, 12
IX	15
X	13, 16
XI	17, 18, 14, 2
XII	21, 20, 19

2. Within a region, assign according to largest task first.

E. At the end of each station assignment, decide if the time utilization is acceptable. If not, check all tasks whose predecessor relations have been satisfied. Determine if changing these for any task(s) within the station whose predecessor region(s) are equal to or earlier than the tasks being considered for entry into the station, will increase the utilization. If yes, make the change. This station assignment is now final.

Table 2 gives the solutions for the example network shown in Figure 13 such that the workload is evenly balanced among five work stations (jobs) and the cycle time achieved is 21 time units. This algorithm has been automated and will be included as part of Product 5.

Steps 9 and 10 in the job forming process for Category 2 tasks are identical to that used for Category 1 tasks. It provides a means for investigating alternative numbers of jobs and assessing the effect of these alternatives on the ability of the system to meet production requirements. An increase in the cycle time required (i.e., reduced production requirement) might result in a need for one less job. Conversely, by adding another job, the cycle time may decrease dramatically. Again, systems designers and Army decision makers need to be aware of such swings in both requirements and performance in order to make rational design decision.

The product of this process will be a listing of the unique jobs that result from Category 2 tasks. With each job will be a listing of the specific tasks associated with the job. Also, for each function consisting of Category 2 tasks, a resource profile will be shown that indicates what each job is required to do, over what time period, and the proportion of the soldier's time that is spent doing the tasks assigned to the job.

<u>Forming Jobs From Category 3 Tasks</u>. Category 3 task clusters are unique in that the "product" is not measured in terms of units produced. These tasks are those that are implicit in the weapon system design or support requirements and are established more by decree than by measurement. For example, the times associated with monitoring or security tasks are seldom based on the time required to perform certain activities. Rather, these times are more likely to be assigned based on location and coverage requirements. Consequently, these tasks must be assigned to jobs based on how well they can be integrated with jobs containing Category 1 or 2 tasks. The process for determining the number of jobs associated with Category 3 tasks is illustrated in Figure 14. The steps are listed below:

Step 1: Specify conditions under which job must be performed.

Step 2. Specify when job must be accomplished.

Step 3. Specify location of job activities.

Step 4. Determine if all tasks can be performed by a single person.

Step 5. Determine if tasks can be combined with another job.

Table 2

Assignment of Category 2 Tasks/Precedence Regions to Jobs (Workstations) (from Bedworth and Bailey, 1982)

Station	Tasks (in order of assignment)
1	1, 3, 4, 2 [Station time = 21]
2	5, 7, 6 [Station time = 21]
3	8, 9, 11, 10, ~~12~~, ~~14~~, 13 [12 and 14 originally assigned for a station time of 20. Task 13 has predecessor assigned (9) and so was interchanged with 12 and 14 to give a station time of 21]
4	12, 15, 16, 18, ~~14~~, ~~19~~, 21 [Original Assignment did not include 21 (station time of 19): 21 was interchanged with 14 and 19 to give a station time of 21]
5	14, 17, 19, 20 [Station time = 21]

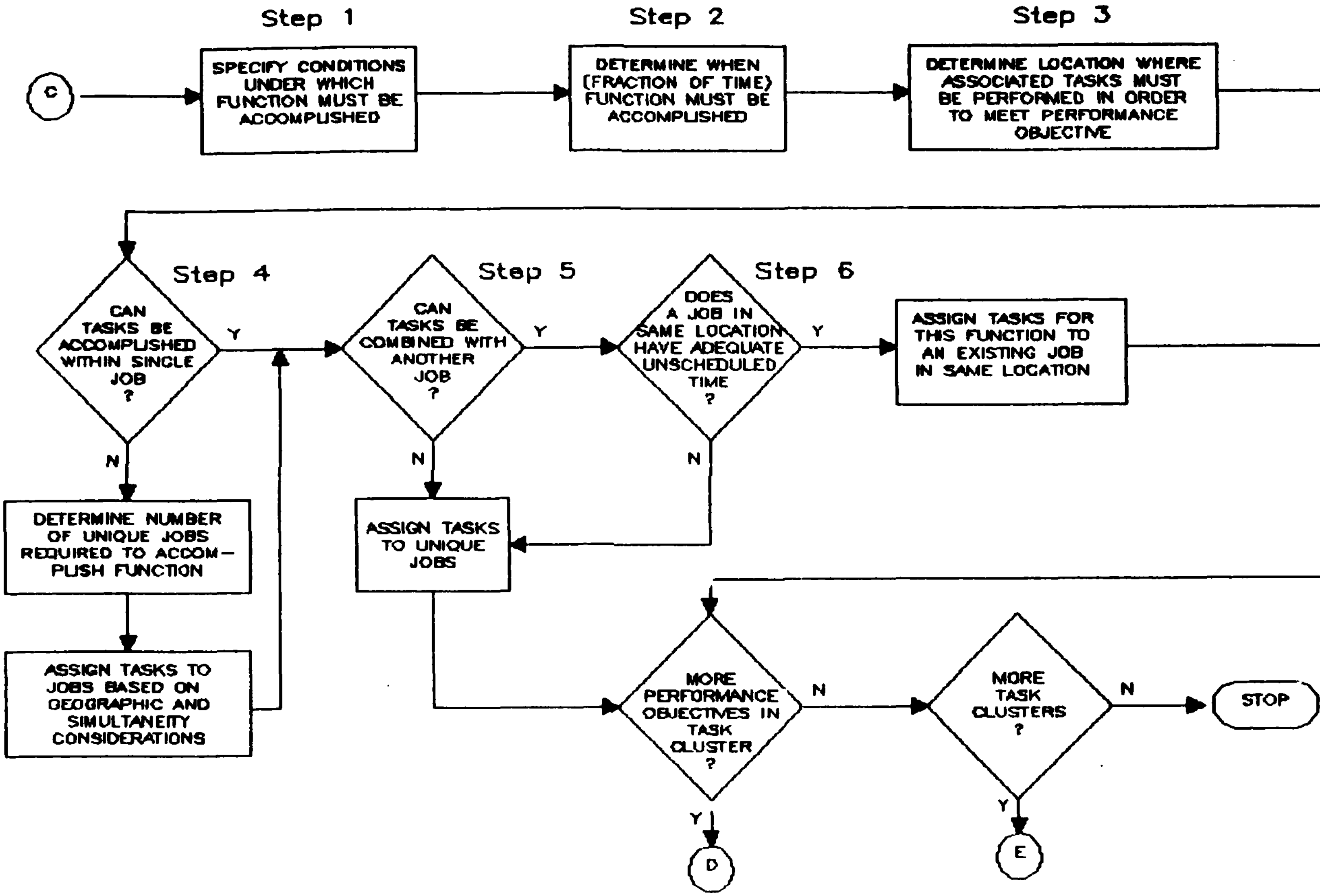


Figure 14. Process for Converting Category 3 Task Clusters Into Jobs.

Step 6. Determine if tasks can be combined with another job in the same job location.

If a Category 3 task is essentially a full time commitment, it constitutes an entire job. If it is a task that can be performed "as time permits," it may be easily combined with another job that requires less than all of an operator's or maintainer's time. Obviously, Category 3 tasks can only be added to another job if they do not conflict with other tasks already assigned to the job. For example, piloting an aircraft is a Category 3 task because it is largely a monitoring and reacting task with a duration dependent on the distance traveled and the conditions experienced during the course of the flight. Other tasks (e.g., navigation, targeting) may be combined with the piloting task to the extent that they do not degrade or interfere with piloting responsibilities. An aircraft design will significantly affect the ability of the pilot to perform these additional tasks. If the piloting task consumes essentially all of the pilot's attention, other tasks that must be accomplished while the aircraft is airborne cannot be assigned to the pilot and, therefore, must be assigned to a different job.

The process for converting Category 3 tasks into jobs focuses primarily on specification of the tasks that must be performed. This activity is shown as three separate steps in Figure 14. Step 1 is a specification of the conditions under which the function must be accomplished. Step 2 is a specification of the time during which the tasks are performed. Step 3 is a specification of where the tasks take place.

Steps 4, 5, and 6 require user answers to up to three questions (defaults are provided). Step 4 asks if the tasks can be performed within a single job. The user must determine whether or not the demands of the tasks are such that more than one job is required in order to accomplish them. For example, if constant 360-degree surveillance of a target area is required, more than one job may be required to provide the necessary level of attention. Step 5 asks if the tasks can be combined with other jobs. Some Category 3 tasks may consume less than 100 percent of the operator's or maintainer's attention and can be performed either simultaneously or in conjunction with Category 1 or 2 tasks. If this is possible, the Step 6 question must be asked--does a job in the same location have adequate unscheduled time to permit combining Category 3 tasks with it. If so, the Category 3 tasks are overlayed onto the other jobs that will permit the additional demands.

Category 3 tasks require the greatest amount of user judgment in determining the number of unique jobs required to accomplish them. However, they are likely to represent a relatively small portion of the total workload associated with the operation and maintenance of a weapon system and are most likely to be associated with command, supervisory, security, and monitoring activities.

Summary

The process of converting job clusters into unique jobs is accomplished by first cluster-analyzing the tasks to establish their interrelationships, then identifying the type of tasks in each cluster, and applying several widely accepted and commonly used techniques for assigning tasks to jobs. This process permits some experimentation with alternative job configurations so that the impact of changes in system requirements or crew sizes can be addressed. All of the tools proposed can be implemented in an automated environment so the both the time required to assign tasks to jobs and the user effort is held to a minimum. The data required to employ these procedures is system performance objectives, tasks, task sequence, and task times. The result of these analysis is an objective, replicable means for assigning tasks to jobs so that potential design shortfalls can be identified early and corrective actions can be initiated.

USER TIME REQUIREMENTS

The amount of time it takes a user to obtain an output from Product 5 is mostly dependent on the amount of time it takes for the user to obtain and enter input data. First, the user must obtain documentation with information about system performance objectives, task list, sequence, and times. Some users will have obtained the needed documentation through the normal course of their jobs. Other users will have to request documentation.

Next the user begins the process of data entry. The user will begin a run by entering identification data about the system under study. The user will create a new file on the first run, and will retrieve the file on subsequent runs. This process will take a minute or two.

The user will be prompted to enter system performance characteristics, one by one, as well as their associated tasks, in sequence, with task times. As mentioned earlier, the user can fall back on the system's prompts, help function, and default task time data base to make this job easy. The user will be able to enter an exact performance objective, for example, or may select values from a menu. A user with straightforward documentation covering only a small number of performance characteristics may be able to enter this information in less than 30 minutes. A user entering data on many performance characteristics may require several hours. On subsequent runs involving the same system, however, the user will not have to enter data that have not changed, and thus, subsequent runs will be shorter.

With all input data entered, the user can request a printout of the task clustering matrix and spend time reviewing it. This review can be done quickly, or could take a day or so if colleagues were consulted. Next, the user initiates the clustering process. The computer will display a friendly status message so the user can track system progress. The time it takes the computer to generate a clustering output depends on the size of the performance characteristics by tasks matrix. A matrix of 50 performance characteristics and 10 tasks would be processed in a matter of a few minutes, given the gigabyte memory card and hard disk for storing the internal files produced by the cluster process. A matrix of 100 characteristics and 100 tasks could likely be processed in under 1/2 hour. Processing times would be reduced if the user's PC terminal were connected by modem to a mainframe, but that is not required.

The user will be able to interrupt the process at this point, but the system can be instructed to proceed straight to the process of forming unique jobs. As mentioned earlier, for Category 3 task clusters, the user will be asked to answer three simple questions about the tasks under study. However, the Product can provide default answers if needed. The job formation process can be expected to last under 1/2 hour, depending on the amount of data involved. While 1/2 hour may sound like a long processing time for a PC, given the current capabilities of the machines, this is well within its limits.

How does this projected user time requirement compare to the time it presently takes people to generate manpower estimates? Some people can

provide manpower estimates in a matter of seconds by providing the same manpower requirements of systems well known to them. However, as more and more data become available about the new system, such a quick method of solution is likely to produce erroneous estimates. More thorough analyses of manpower estimates take about a week using an informal comparability approach. This is manual, unsystematic, and provides no audit trail.

In summary, Product 5 can be used quickly or the process can take several days if the user has to wait for documentation and then wants to enter in all available data. In terms of accuracy of the manpower estimates produced, Product 5 will produce reliable estimates which are derived from the design of the system itself. The time spent in using Product 5 will not exceed the amount of time spent on a careful manpower analysis. In addition, Product 5 output will be as accurate as possible given existing documentation, and will allow for an audit trail.

USER TRAINING

We propose to build into the software and data bases of Product 5 two components that will enable users to learn and use the capabilities of the product. The first is a comprehensive Embedded Training capability. The second is a context-sensitive Help and Explanation capability. We anticipate that the two components will share many data elements and software routines, since their purposes and functions are basically similar.

Embedded Training Capability

The embedded training capability will be accessed from the operating system level. A unique command will be provided to call up and begin the embedded training component, separate from normal product functions. This capability allows "off-line" training to prepare new users of the product to learn its functions and capabilities, as well as review or sustainment for more experienced users.

The Product 5 embedded training component will contain modular lessonware. Specific topics will be organized into lessons, which can be taken independently by a user. An overall syllabus structure will guide initial training, but the user will not be constrained to take the training modules in any specific order. Following the syllabus structure for new users will be encouraged, however.

The following major lesson topics will be included in the syllabus:

- Basics I - Introduction to the Manpower Estimation Method and Software System
- Basics II - Input Data Requirements and Data Input Practice
- Basics III - Understanding and Interpreting Manpower Estimates
- Advanced Topics I - How System Tasks are Clustered
- Advanced Topics II - How Jobs are Formed from Task Clusters
- Advanced Topics III - Sensitivity Analyses: Changing Input Data to Affect Manpower Estimates

The basic modules are designed to enable the new user to use the product to derive manpower requirements from system design estimates. The advanced modules are for more experienced or interested users, or those who need to use the more advanced capabilities of the product.

Guided practice and sample solved problems will be included in the function. Much of the training provided by the component will consist of hands-on exercises with extensive guidance for the user. Exercises will concentrate on accomplishing specific steps of using the product, and will contain error diagnostics (comparing the user's performance with that of an idealized Product 5 user) to enable feedback and learning from errors.

The function will contain a balanced mix of knowledge and hands-on training. Some users will be uninterested in how the product works and will wish to emphasize practical capabilities. Others will develop an interest in how the product does what it does to produce its outputs. The content and structure of training will accommodate both extremes, as well as many intermediate points on the "theory-practice" continuum.

When users are tasked to develop manpower estimates, it is likely that a timely response will be particularly important. Thus, we will structure training to enable the user to work with basic features and capabilities of the product first. If the user later has later has time and interest, he or she can "add on" training in how to work with such features as the sensitivity analysis capability.

An additional function is "checkpoint and resume." The product's users are busy people with many demands on their time. We will therefore not constrain the user to dedicate time to complete even a single module of training at one session. Each user's progress in training will be monitored by a control feature in the component, and a user will be able to suspend training at any point and resume from the same point at a later time.

We anticipate that the component will be capable of enabling a completely naive user to develop basic, "no-frills" manpower estimates for a new system after a maximum of four hours training time. The advanced lessons will take approximately 1-2 hours each.

Context-Sensitive Help and Explanation Facility

This facility will enable the user to request help and explanations at any time the user is actually interacting with Product 5. Context sensitivity of this feature refers to the fact that the product will have information about what the user is attempting to accomplish during any interaction. Using this information, the product will provide guidance and explanations of how to accomplish the particular function. The product will also be able to present information regarding why particular inputs and judgments are needed to accomplish the interaction. Guidance will always be provided when the user invokes the help capability. "Why" information will only be presented at the explicit request of the user.

The user interface with the help and explanation capability will be through a "hot-key" approach, with one function key (or the equivalent) always set aside to request help. If the information contained in the help or explanation requires more than one full display screen to present, the user will use the normal up and down cursor-control or scrolling keys to move forward or backward through the information presented. If there are options, choices, or responses associated with a help or explanation display, the user will be presented with a "pull-down" menu of choices, above the normal display area for help information. Choices will me made by moving a block cursor to the desired option or response (using the left and right cursor control keys) and using an "enter" or execute key to invoke the choice desired.

As mentioned in earlier sections, the help function will provide assistance in entering input data. These help screens will lead the user to structure input data properly.

USER ACCEPTANCE PLAN

The Product 5 User

At present, manpower estimates are developed by AMC and TRADOC and monitored by DCSOPS with concurrence from DSCPER. In AMC, the Engineering Section develops Basis of Issue Plan Feeder Data (BOIPFD). The New Equipment Training Section of the major supporting command develops the Quantitative and Qualitative Personnel Requirements Inventory (QQPRI) which relates to manpower requirements. Based on the major support command draft BOIPFD and QQPRI, HQTRADOC through the integrating centers will charge the combat and training developers. The combat developer provides comments on the draft proposed job specifications furnished by the materiel developer. The combat developer provides justification for any change to the QQPRI. The training developer provides an estimate of the amount of formal on-the-job training required (TRADOC Form 799-R). HQTRADOC will provide copies of the QQPRI along with the school and integrating centers' comments to the Equipment Authorization Review Activity (EARA). EARA forwards this to the Project Manager and New Equipment Training personnel. Three additional copiesbare sent to Soldier Support Center, National Capital Region (SSC-NCR). SSC-NCR develops the proposed operator and maintainer decision regarding new or improved equipment. HQTRADOC will send the documents received from SSC-NCR to HQDA for approval. DCSOPS with DCSPER concurrence has the final approval.

The DCSPER MANPRINT personnel responsibilities are evolving given that the MANPRINT system is relatively new as an institutional entity. However, MANPRINT office personnel are concerned with developing and monitoring manpower requirements of new systems. At present, the Manpower Requirements Determination Module of the Man Integrated Systems Technology (MIST) package is used by MANPRINT personnel (both in the government and by contractors) to develop maintenance manpower estimates. However, Product 5 may be seen as a more helpful tool. MIST estimates manpower requirements by determining the number of maintenance man-hours required of each MOS to support the system for a specified time period, adjusted for individual work capacity. MIST then computes the number of people who must be available per MOS by dividing the requirement by an availability factors. The Product 5 approach is distinguished from the MIST approach in that the Product 5 approach produces the number of personnel required to support both operations and maintenance jobs, and bases these estimates on system design requirements, rather than basing the projection on the percent of available MOS required.

Potential Product 5 users, military and civilian, then, will be found in several Army agencies. The assumption is made that the system must be friendly to maximize its chances for adoption. In addition, the assumption is made that each user will have available input data at varying levels of development. Therefore, Product 5 is designed to provide output using data ranging from scant to sophisticated. The discussion below describes our approach to providing potential users with a Product 5 that they will accept.

Causes and Results of Poor User Acceptance

Even when the performance of software design is excellent, the problem remains of how to encourage its use in the field (Donnell, Fineberg, and Carter, 1987). Procedures for improving implementation and use require an understanding of the user's attitudes and perceptions toward the product and its use. The user's background and experience with computers affect user acceptance. The fit of the product within the context of the existing job situation will affect user acceptance. If the user detects conflicts between product use and existing doctrine, acceptance will be poor. Finally, product performance will affect user acceptance. The product must run reliably with little downtime and product outputs that are correct.

Some of the specific problems listed in Donnell et al. (1987) that may cause poor user acceptance include:

- Lack of user confidence, reflecting perceived unreliability, often resulting from failures, errors, or breakdowns in the sensitive early stages of system introduction.

- Divergence from perceived function, where the hardware or software manifestation of the system is at odds with the user's idea of what it does or should do.

- Divergence from individual needs, where the user feels that his or her specific requirements, preferences, tastes, etc., are ignored or even offended by specific system characteristics.

- Divergence from individuality, where the user feels unable to influence the system personally.

- Threat to privacy, where the user feels he or she is liable to some form of exposure (data or decisions) as a result of system use.

- Threat to security of self-esteem. Of particular importance to acceptance, this often reflects the reluctance of well-placed users to make themselves look foolish by failing to master seemingly complex new technology. It may also reflect a personal conclusion that one's job is vulnerable to computer encroachment; or, alternatively, that computer use diminishes the status of that job by incorporating menial elements.

Poor user acceptance results in a variety of user responses. A list of common responses is presented in Figure 15. If user acceptance problems are discovered before the system is fielded, solutions will be easy to remedy. One of the major goals of Product 5 is to avoid user acceptance problems early in the development process. To do this it is essential that measuring user acceptance be an integral part of all Product 5 development efforts.

User acceptance of computer systems is a frequently neglected aspect of software evaluation. User acceptance is a function of ease of use and perceived usefulness of output. The software developer typically evaluates product effectiveness in terms of speed, accuracy, quality of output, and

Response	Definition	Comments
Dis-Use	Reliance on other information sources.	Requires existence of alternative information source, user with sufficient discretion.
Mis-Use	"Bending the rules" to short-cut operational difficulties.	Requires significant knowledge of system. May negatively impact system integrity.
Partial Use	Use of (perhaps inappropriate) subset of system capabilities.	Users frequently adopt "satisficing" strategy, may not learn most relevant system capabilities.
Distant Use	Interposition of operator between user and system.	Requires high status and discretion. Typical response of managers.
Modification of Task	Changing the task to match capabilities of system.	Prevalent when tools are rigid, problem, is unstructured, as in scientific problem solving.
Compensatory User Activity	Compensation for system inadequacies by additional user actions.	Typical with users of low discretion, as clerks.
Direct Programming	Programming by user, in order to modify system capabilities to suit needs.	Typical response of computer-sophisticated user, as scientific and engineering user.
Frustration and Apathy	Response of user when above actions are inadequate or unsatisfactory.	Involves lack of user acceptance, high error rates, poor performance.

Figure 15. User Responses to Inadequate System (from Ramsey and Atwood, 1979).

the extent to which it improves human performance. However, users reject even highly effective software systems for any number of reasons. Two important reasons are ease of use and perceived usefulness. Therefore, the software developer alone cannot judge the effectiveness the the product. Users must also judge the product as easy to use and useful.

Designing for Ease of Use

The general notion of user acceptance includes both ease of use and perceived usefulness. Another way to view this issue is in terms of reliability of use and validity of output. If a software system does not have both these attributes, then it will not be accepted by the user. Four areas will be considered in evaluating ease of use: the skill levels of potential users; the type and specificity of feedback given to users; the consistency between what users request and what they receive, and memory demands the software system places on users (Liffick, 1985).

Based on an operator skill evaluation, the user interface will be designed to match the skill of the users. The interface will provide embedded training for the novice user. The information the novice user must have to make a decision must be known and available. Experienced users may need less information in order to use the system. Given the newness of this software system, it can be assummed that users will be novices. Therefore, it will be necessary to create a dynamic system, one that changes as the user becomes familiar with it. Product 5 will include separate tracks for different user experience levels.

The points at which a novice user becomes an experienced used is not easy to define. It is usually not the case that one day the user is a novice, and the next he or she is experienced. Even an experienced user might want to use a feature he or she has not tried before, and regress briefly to the novice stage. Product 5 will allow an experienced user to function as a novice, on demand, then return to the experienced used mode. Switching from experienced to novice mode will be simple, and the user will clearly know where he or she is in the system.

Information to the user is critical in ease of use. Menus and feedback provide the information the user needs to navigate through the system. Systems described as user friendly are usually menu oriented. Feedback, no matter how simple, is important to keep the user informed about every action that has been requested. Feedback lets the user know what the system is doing, so the user knows that what has been requested has been accomplished. Given the many suspicions that novice users tend to have about computers, this is important. All feedback should be positive. When the user has done something incorrect, the system will clearly identify the incorrect action as well as a direction about how to continue. This keeps the user from having to guess what to do next.

User effectiveness is increased where there is consistency in rules, and little ambiguity. Ambiguity requires the user either to make a decision with incomplete information, or waste time searching the documentation for a resolution to the ambiguity. Therefore, consistent procedures will be

established for user interactions. The consistent use of rules will allow the user to make assumptions about how things work within the system.

It is important to minimize the demands on human memory. A help function for the user is the ideal way to limit memory requirements. Such a function can usually be entered at any time by the user. The help function provides details about how each part of the system works, what the various commands of the system are, and what what the formats for inputs are. If the user needs more information than is provided in the help function, he or she will also have the option of entering novice mode. As mentioned above, the user will be able to return to experienced used mode when the additional help is no longer needed.

Enhancing Perceived Usefulness

Participation in product design by the user may well lead to a match between what the software developer sees as effective and what the user sees as useful. User acceptance is a combination of reliability, ease of use, and validity and perceived usefulness of output. No single one of those is sufficient for user acceptance. For example, the Product 5 user may find Product 5 easy to use, but of no particular value. In that case, user acceptance is low. In contrast, the user may find the product difficult to use but of great value; the user may struggle to use the product, but user acceptance will be low.

The concept of product usefulness may be measured subjectively and objectively. Subjective measures evaluate the attitude of the user toward the product, e.g., is the product helpful? is it difficult to use? does it seem to be effective? Objective measurments can also be taken. Variables to be measured objectively should be directly related to the user's job and measurable by the software developer, for example, frequency of use, length of session, use of output, and improved human performance. By selecting job relevant dimensions to measure, there is a good chance that the effectiveness sought by the software developer will closely match the perceived usefulness of Product 5 by the user.

Assessment of User Acceptance

User acceptance of Product 5 will be measured objectively and subjectively. A subjective assessment indicates how satisfied the user is with the system, and is accomplished through user interview and questionnaire responses. An objective assessment indicates how much the user uses the system, and is made by monitoring actual system use.

Subjective data concerning user accepance can be obtained via structured interviews or questionnaires. User acceptance and product usefulness are the two broad categories used in subjective evaluation (Donnell et al., 1987). Users will be asked to rate Product 5 on the following dimensions of user acceptance.

1. The system is matched to the user.

2. The system provides the critical variables needed to solve the problem.

3. This product can handle a typical, complex manpower estimation problem.

4. The product does not add to the already considerable information overload within the operational and organization planning effort.

5. Use of the product will not require more expertise from the typical user than is likely to be available in the operational environment.

6. People can easily under the procedures to be followed in using Product 5.

7. The product provides a common language, facilitating easy communications between members of the decision making team.

8. The product contributes to the essential flow of intergroup information, or communications, necessary for effective decision making.

9. The use of the product is consistent with, and would not interfere with operational and organizational planning.

10. A user can be confident in Product 5 decisions.

11. If implemented in an operational environment, use of the Product 5 can be expected to increase as time progresses.

12. The use of Product 5 in an operational environment is a realistic goal for the near future.

Product 5 users will also rate the Product on the following dimensions of product effectiveness:

1. Product 5 enables sufficiently rapid and complete responses to aid the manpower estimation process.

2. Product 5 encourages the user to explicitly identify relevant objectives and to prioritize them.

3. Product 5 encourages effective response to the issues most relevant to determination of manpower requirements of system designs.

4. A Product 5 user can readily prepare data, input data, and extract understandable results.

5. Product 5 encourages the decision maker to consider a wide range of options or possible system alernatives.

6. Product 5 encourages one to think critically and realistically about problems and prospects for implementation of the selected decision.

7. Product 5 focuses and enhances appropriate and constructive decision maker discussion concerning the issue under consideration.

8. Product 5 possesses considerable generality so that many different problems can be relatively easily accommodated.

9. The value of the product will increase as the complexity of problems to which it is applied increases.

Objective measures of user acceptance, such as the duration and frequency of user sessions, and the time taken to generate a manpower estimate, should also be studied. This will be done in as unobtrusive manner as possible, with no demands placed on the user's time.

Involving the User in Development

The Product 5 team has identified likely users of the product. These people will be consulted during product development. This will prevent potential users from feeling as though the Product has been forced upon them by outsiders, a quick guarantee of user rejection. The Product 5 approach does not burden Army subject matter experts. Therefore, we will be able to use our meetings with potential users to let them critique the approach and our plans for development and implementation. In addition we plan to test Product 5 with in-house Army experts to avoid presenting a product that looks "civilian." Our goal is to provide potential users with a reliable, simple to use product, that immediately offers them help in improving their jobs. We plan to set up a "User Interest Group" that will remain together from the detailed design phase to production and implementation.

PRODUCT 5 DEVELOPMENT CYCLE

Overview

The software development of Product 5 must be evaluated to assure that it meets all functional requirements. The software must have: the type of data the user needs, algorithms which include variables important to the user, decision rules formulated using experts, and output that is accepted by the user because it makes sense and is useful. The software developmental process keeps the end user in mind.

The Product 5 lifecycle validation, verification, and testing (VV&T) process, including software development and maintenance, will ensure software quality, user acceptance, and ease of use. The VV&T process is a procedure of review, analysis, and testing used throughout the software lifecycle. Validation determines the correctness of the final program or software with respect to the software requirements. Verification employs integrity and evolution checking to determine internal consistency and completeness. Testing, either automated or manual, examines program behavior by executing the program on sample data sets. The software lifecycle is the period of time beginning with the software concept development and ending when the resultant software products are no longer avalable for use.

The software VV&T cycle is broken into five phases: requirements determination, design, programming and testing, installation, and operations and maintenance (Federal Information Processing Standards Publication, 1983). These five phases represent milestones in the software development process, and provide excellent points for user inspection. Use of these five phases improves direct project management. Software developers and maintainers have a well defined set of tasks to perform. Verifiers, by checking the products of these tasks, can verify that the project requirements are met at each of the five phases. Table 3 presents an outline of lifecycle VV&T activities.

Phase I. Requirements Definition and Analysis

This phase consists of four parts: development of the project validation, verification, and testing plan; generation of requirements-based test cases (scenarios); review and analysis of the requirements, and review and analysis of the draft user manual(s).

The project plan explains the strategy for managing the development of the software for Product 5. This document defines the general software development process for all phases of the project, estimates resource requirements, and specifies intermediate milestones, including management and technical reviews. It defines methods for design, coding, verification. validation and testing, document reporting, and change control. A basic set of test cases will be developed to clarify and to determine measurability of each software requirement. The acceptance criteria developed during subject

Table 3

Lifecycle VV&T Activities (from Federal Information Processing Standards Publications, 1983)

PHASE I. Requirements Definition and Analysis

- Developmemt of the project verification and validation plan
- Generation of requirements-based test cases
- Review and analysis of the requirements
- Review and analysis of the draft user manual

PHASE II. Design

- Completion of Verification and Validation plan
- Generation of design-based test scenarios
- Review and analysis of the design
- Premliminary design integrity check
- Preliminary design evolution check
- Development of test support software

PHASE III. Programming and Testing

- Completion of test case specification
- Review, analysis, and testing of the program
- Code integrity check
- Code evolution check
- Unit test
- Integration test
- System test

PHASE IV. Installation

- System acceptance

PHASE V. Operations and Maintenance

- Software evaluation
- Software modification evaluation
- Regression testing

matter experts will be used to develop the test cases. Input data and expected results for each test case will be included in the specification.

The software requirements document will specify what the system must do, including the requisite information flows, processing functions, performance constraints, and the acceptance criteria for deciding that specific requirements have been satisfied. Subject matter experts and software developers will work together to develop this knowledge base structure. In addition, this document will also contain those internal specifications which, although transparent to the end user, are necessary for the development of the end product. Project requirements are reviewed for clarity, completeness, consistency, testability, and traceability to the problem statement. This activity ensures that the requirements result in a practical, usable solution to the appropriate area.

Analysis techniques in the requirements phase include static and dynamic analysis. Static analysis focuses on checking adherence to specification conventions, consistency, completeness, and language syntax. Dynamic analysis focuses upon information flows, functional interrelationships, and performance requirements. Manual methods such as inspections, peer reviews, and "walkthroughs" are effective in accomplishing both types of analysis. If the constructs of the requirements specification scheme are clearly defined and capable of being represented in a computer processable form, then automated tools may be used to perform both static and dynamic analyses.

User manuals will be drafted. Each will describe software system use for each product in non-technical language. Each manual will describe both the system functionality and the user interface. Manual preparation during the requirements phase is an excellent mechanism for ensuring that both the users and the developers share the same view of the system. The manual serves as a reference document for the preparation of input data and as a useful tool in setting parameters for interpretation of the results. The users' manual will be reviewed for clarity and consistency. It will be checked for completeness against the requirements document. In addition, this verification activity will ensure that the internal specifications of the requirements document are defined sufficiently to produce the functions and interfaces described in the users' manual.

Phase II. Design

The purpose of the design phase is to generate a complete solution to the Product 5 problem. The best solution has already been selected. During design specification, a high-level specification is developed which defines information aggregates, information flows, logical processing steps, and the solution in terms of algorithms and data structures. The result is a solution specification that can be implemented in code with little additional refinement.

The design specification contains two parts: (1) a preliminary design section to identify the high-level solution, and (2) a detailed design section that defines software (algorithms and data) to be coded in

the subsequent phase. The design will be analyzed to ensure internal consistency, completeness, correctness, and clarity, and to verify that the design, when implemented, will satisfy the requirements.

As incorrect, inconsistent, infeasible, or ambiguous requirements are discovered, revised requirements specifications will be developed. The detailed design plan may indicate the need for additional testing. Additional test scenarios and test cases (input data and expected results) will be developed to exercise and test logical and structural aspects of the design. Development or acquisition of any support software needed for unit, integration, or system testing will be completed and installed during the detailed design phase to ensure readiness during programming and testing.

Design specification schemes specify algorithms and their inputs and outputs in terms of modules. Inconsistencies in specifying the flow of data through the modules can be detected by static analysis techniques. Dynamic analysis of the design is accomplished by simulation. This may be a manual "walkthrough" or an automated simulation using a model of the design. The higher the model fidelity, the higher the cost of the simulation. This cost generally increases with the complexity of the model. Formal analysis techniques involve tracing paths through the design specification and formulating a composite function of each. The purpose of deriving these composite functions for a given level of design is to compare them to the functions of the previous level. This process ensures that the design continues to specify the same functional solution as is hierarchically elaborated in the schematic decision tree presented in the user manual.

Phase III. Programming and Testing

During this phase, the detailed design is implemented in code, resulting in a program or system ready for installation. Three tests are performed on the software: unit, integration, and system. The programmer is responsible for unit testing. The project manager determines the responsibility for integration and system testing, depending on the project size and criticality.

Unit testing looks for typographic, syntactic, and logical errors in the code. Programmers will also check to ensure that each module correctly implements its design and satisfies the specific requirements. Static analysis techniques and tools are used to ensure the proper form of code and documentation. Dynamic analysis techniques are employed to study the functional and computational correctness of the code. Initially, manual "walkthroughs" can be used as an effective forerunner to testing. Testing for adherence to assertions, produced during design, is important during this phase.

Integration testing focuses on checking intermodule communication links and on testing aggregate functions formed by groups of modules. System testing examines the operation of the system as an entity, and in a simulated environment. This ensures that the software requirements have been satisfied both singly and in combination with other "real life" variables found in the user's environment. Sample data will

be used in testing initial prototypes. These sample data tests evaluate the procedures, decision rules, and algorithms chosen for use in the product.

The final activity of this phase is to ensure readiness of the software installation, including revision of plans as necessary and completion of all other coding, testing, and documentation. Fully documented and tested code is constructed and prepared for installation. Manuals describing the input and report formats, user commands, error messages, and instructions for operation by the user are completed. Final revisions and additions to the test data are made. Based on prototype testing, recommendations for revisions are made; subject matter expert input is important. Retesting ensures confidence in the results and demonstrates ease of use. Actual results are compared with expected results to validate the product's output. Results of validation testing are documented. Problems are recorded formally and resolved as necessary.

Phase IV. Installation Phase

This phase evaluates and modifies software, if necessary, to ensure user acceptance. To accomplish this, the system is placed in operation. The final step, integrating the system components, includes installing hardware, installing the program on the computer, reformatting/creating the data base, and verifying that all components have been included. Modification of the program code may be necessary to obtain compatibility between hardware and software, or between different software modules for which earlier simulation testing may not have been adequate. The installation report describes the results of installation activities, including data conversion, and software and system problems and modifications. User acceptance and user friendliness will be validated.

Next, the system is tested in its complete operating environment. The result is a system qualified and accepted for production use. The installation report also includes operational test results.

Next is the start of system operation. Interfacing with on-going software systems will be a prime consideration to save money and computer storage space, in the likely event that the product computer serves multiple purposes. A strategy for this will be devised. A completely new program could either be phased into operation or could be be implemented at once. This task also includes operator and user training.

Phase V. Operations and Maintenance

The operations and maintenance phase is the time of actual use of the product in the operational environment. User evaluation continues, and modifications desired are channeled through a formal request for modification process. This project's plan does not call for contractor monitoring through the operations and maintenance phase.

INSTITUTIONALIZING PRODUCT 5

There are two approachs that will be used to institutionalize the product. One is to take "campaign" actions to institutionalize the product, and the second is to build into the product inherent characteristics that will help insure its institutionalization.

Campaign Actions Taken to Institutionalize the Product

The institutionalization plan includes three campaign action items. These are (1) involving potential users in the development process, (2) securing the support of a general officer, and (3) teaching product use to Army personnel within their training courses.

Involving the potential users of the product in all stages of product development occurs first in time. As described earlier, users will be found in AMC, TRADOC, DCSOPS, and DCSPER. Potential users will be involved in the design and testing stages through both informal commenting and more formal pilot-testing. A frequent dialogue will be established with the more cooperative potential users. They will be asked for input on data base items and structures and interface design. In addition, their opinions on the more basic procedures of the product will be sought.

These are three reasons for the involvement of the potential users. First, their involvement helps to develop a critical mass of positive potential users prior to the availability of the product. They will help institutionalize the product by using it and promoting it. Second, potential users help tailor the product to their needs and desires. This will make it a more attractive product and thus help insure its institutionalization. Finally, Product 5 developers want to be able to say we consulted with the users in the development of the product and that we have their support and approval.

The second campaign action item will be to obtain the support of a general officer. This will be accomplished after the product is partially developed so that its rudiments can be shown and demonstrated. Also, the support of the users will help gain the support of a general officer. In addition, briefings the efficiency, cost effectiveness, and other benefits of the product will be given as needed.

The third campaign action item is to have the use of the product included in the courses taught to Army users. It should be possible to include a new module in these courses specifically devoted to promoting the product. In addition, besides promoting the product, the course will teach Army personnel how to use the product and make users familar and comfortable with it. All of these additions to Army courses will help institutionalize the product.

Inherent Features Fostering Institutionalization

There are four features which will be inherent characteristics of the product or results it will yield. All four will foster its institutionalization. They are:

- Face valid
- Lowers cost of Army personnel manpower estimation
- Lowers cost of system development
- Produces a formatted audit trail

Face validity will come through interaction with the users during the development and testing of the product. Face validity will go a long way toward institutionalizing the product. Face validity will partially result from the users' feedback. Such feedback will provide guidance for the the design and development of the product. Thus it will have the look and feel of the users.

In many cases, the product will result in a reduction of the amount of labor required to produce accurate system manpower estimates. This feature of the product will almost in and of itself cause it to be institutionalized. Many system development efforts have resulted in elegant systems that were never used. Often this was because the systems required the users to do more than they did before. On the other hand, everyone appreciates a job aid that actually makes their job easier especially if it is because they have to do less. The reduced labor will result in a less costly manpower estimation process.

Similarly, the product will lead to a lower cost for the evaluation of system designs than was previously experienced. This will be the result of having specific manpower estimates available before system production, alleviating costly modifications that would have to occur if manpower requirements of the new system were excessive. Thus will be avoided any costly redesign efforts prior to developmental testing and any retro-fitting after operational testing. In addition, examining manpower estimates before production also will help the system avoid having to undergo the typical product improvement efforts after fielding. All of these reduced cost aspects will be effective in obtaining the support of a general officer.

The product will result in a formatted audit trail which will document each system manpower estimation effort. This will be an especially attractive feature of the product, because the present process often leads to poorly answered questions about manpower requirements. Part of the reason for the present process resulting in poorly answered questions is that the process is not proceduralized. The present process provides no format or easy to use vehicle for generating an audit trail.

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APPENDIX A

KAPLAN & CROOKS TAXONOMY

SYSTEMS MISSIONS
(Categorized by Class of System)

SYSTEM MISSIONS

AIR DEFENSE WEAPONS including: Short Range Missiles, Medium Range Missiles, Long Range Missiles, Air Defense Guns, High Energy Systems

1. Destroy aircraft.
2. Confuse and disrupt aircraft.
3. Deny selected airspace/formation to attacking aircraft.
4. Destroy ground targets.
5. Protect operator/crew from enemy action.

ARMORED VEHICLES including: Main Battle Tanks, Armored Reconnaissance Vehicles/Light Tanks, Infantry/Cavalry Fighting Vehicle, Armored Personnel Carriers Mounting Anti-Tank Weapons

1. Destroy fixed emplacements.
2. Destroy armored vehicles.
3. Destroy enemy personnel.
4. Destroy/disrupt enemy aircraft.
5. Suppress/disrupt enemy activity.
6. Serve as a platform for mounted attack.
7. Transport troops/materiel.
8. Perform reconnaissance.
9. Protect crew/passengers/materiel from enemy action.

AVIATION SYSTEMS including: Attack Helicopters, Scout Helicopters, Transport Helicopters, Utility Helicopters, Fixed-Wing Reconnaissance, Fixed-Wing Transport

1. Destroy enemy vehicles.
2. Destroy anti-aircraft systems.
3. Destroy fixed emplacements.
4. Destroy enemy personnel.
5. Disrupt/suppress enemy activity.
6. Perform reconnaissance.
7. Serve as platform for electronics warfare systems.
8. Transport troops/materiel.

AVIATION SYSTEMS (Continued)

9. Transport injured troops.
10. Protect crew/passengers/materiel from enemy action.

BATTLEFIELD COMMUNICATION SYSTEMS including: Man-Portable Radios, Vehicle-Portable Radios, Visual Communications Systems, and Base Radio Systems

1. Transfer information and orders between concerned units/individuals.
2. Protect system/crew from enemy action.

C^2/C^2-I SYSTEMS including: Field Artillery Fire Control, Tank Fire Control, Air Defense Fire Control

1. Provide information on current battlefield conditions and situation.
2. Provide projections of probable future conditions and enemy behavior.
3. Control the behavior of friendly forces.
4. Manage friendly weapon operation.
5. Manage logistics.
6. Communicate information to appropriate units.
7. Protect system/crew from enemy action.

COMBAT/TACTICAL SUPPORT EQUIPMENT including: Combat Engineer Vehicles, Recovery Vehicles, Demolition Equipment, and Bridging Equipment

1. Destroy/remove obstacles/roadblocks.
2. Construct obstacles/roadblocks.

SYSTEM MISSIONS

COMBAT/TACTICAL SUPPORT EQUIPMENT (Continued)

3. Bridge obstacles.
4. Construct emplacement/shelters.
5. Transport command posts.
6. Transport damaged vehicles.
7. Destroy armored vehicles/ personnel.
8. Protect crew/material from enemy action.

ELECTRONIC WARFARE AND SURVEILLANCE SYSTEMS including: Countermeasures Equipment and Sighting and Surveillance Equipment

1. Provide critical information on potential targets.
2. Confuse/disrupt/disable enemy systems.
3. Protect operator/crew from enemy action.
4. Jam electronic signals.
5. Produce false targets/target signatures.

GROUND TRANSPORTATION EQUIPMENT including: 1/4 Ton Utility Trucks, 3/4 to 1-1/2 Ton Trucks, 5 Ton Trucks, 8 to 10 Ton Trucks, Heavy Equipment Transport Trucks

1. Transport command personnel.
2. Transport troops.
3. Transport materiel.
4. Serve as an ambulance.
5. Protect operator/crew from enemy action.

INFANTRY WEAPONS including: Pistols/ Revolvers, Rifles, Sub-Machine Guns, Machine Guns, Recoilless Rifles, Anti-Tank Missile Systems, Anti-Aircraft Missile Systems, Grenades/Grenade Launchers, Anti-Armor Mines, Anti-Personnel Mines, Flamethrowers, Mortars

INFANTRY WEAPONS (Continued)

1. Destroy enemy vehicles.
2. Destroy low flying enemy aircraft.
3. Destroy fixed emplacements.
4. Destroy enemy troops.
5. Disrupt/suppress enemy activity.
6. Provide illumination.
7. Protect operator/crew from enemy action.
8. Conceal friendly forces by making smoke.

ORDNANCE SYSTEMS including: Light, Towed, Tube Artillery; Light, Self-Propelled, Tube Artillery; Medium, Towed, Tube Artillery; Medium Self-Propelled, Tube Artillery; Heavy, Towed Tube Artillery; Battlefield Support Guided Missile; Battlefield Support Unguided Missiles; Multiple Launch, Guided Missiles; Multiple Launch, Unguided Missiles

1. Destroy fixed emplacements on or behind the battlefield.
2. Destroy enemy vehicles/weapons.
3. Destroy enemy personnel.
4. Suppress/deny enemy activity, and deny terrain to enemy.
5. Provide illumination.
6. Conceal friendly forces by making smoke.
7. Protect crew/material from enemy action.

TARGET ACQUISITION AND/OR DESIGNATOR SYSTEMS

1. Provide critical information on potential targets.
2. Designate/illuminate target.
3. Protect system/crew from enemy action.

TEMPLATES OF SYSTEM FUNCTIONS

SYSTEM FUNCTIONS

COMMAND AND CONTROL

1. Representation of battlefield conditions.
2. Representation of status of forces.
3. Projection of battlefield operations.
4. Projection of weather conditions.
5. Selection and ordering of targets.
6. Management of weapon functions.
7. Personnel planning.
8. Logistics recommendations.
9. Selection of friendly forces.
10. Battlefield control of friendly forces.

COMMUNICATIONS

1. Establishment and maintenance of communications.
2. Prevention of interception/jamming.
3. Information routing.

ENGINEERING

1. Vehicle recovery.
2. Obstacle removal.
3. Bridging.

MANEUVERABILITY

1. Navigation.
2. Maneuver in travel.
3. Maneuver in attack/defense.
4. Self-Recovery.

RECONNAISSANCE

1. Information gathering.
2. Fire control-reconnaissance.

TARGET ACQUISITION AND DESIGNATION (PERFORMED BY INDEPENDENT ACQUISITION AND/OR DESIGNATION SYSTEMS)

1. Acquistion of targets.
2. Target information gathering and interpretation.
3. Target behavior prediction.
4. Delivery of designator on target.

TRANSPORTATION

1. Ability to be transported.
2. Delivery of cargo.
3. Loading/Unloading.

VULNERABILITY/SURVIVABILITY

1. Prevention of detection/location.
2. Escape from system.
3. Protection of operator(s), etc.
4. Movement of system, between operations, to prevent location.

WEAPON DELIVERY

1. Target acquisition.
2. Delivery of ammunition on target.
3. Engagement of several targets.

TEMPLATES OF TASKS (OPERATIONS)
(Categorized by System Function)

OPERATIONS TASKS

BATTLEFIELD RECONNAISSANCE

1. Identify key environmental features.
2. Identify current weather conditions.
3. Identify key elements of threat force.
4. Identify essential information for evaluating NBC contamination hazard outer limits.
5. Identify/select routes.
6. Present information about routes which could influence movement.
7. Identify hazards to movement.
8. Identify early warning of enemy threat.
9. Report map changes.

CONTROL OF FRIENDLY FORCES ON THE BATTLEFIELD

1. Determine commander's desired outcome and priorities.
2. Determine the tactics to be followed.
3. Select the most appropriate friendly unit(s) to engage in operation. (The following types of units should be considered: first echelon, reserve, intelligence, counter-intelligence, maintenance, logistics.)
4. Determine travel routes for friendly units.
5. Determine departure and projected arrival times for friendly units.
6. Prepare contingency plans and the situations in which each is to be implemented.
7. Prepare plans, orders, maps and other required documents.
8. Prepare materials for briefing commanders and staffs.

CONTROL OF FRIENDLY FORCES ON THE BATTLEFIELD (Continued)

9. Monitor units' compliance with orders and their progress.
10. Identify critical situations which indicate significant changes in battlefield operations.
11. Update plans/orders as battlefield situation changes.

ENGINEERING-BRIDGING

1. Prepare bridge site.
2. Excavate foundations.
3. Construct bridge abutments.
4. Construct bridge span.
5. Construct/assemble bridge.
6. Prepare bridge for launching.
7. Position bridge transporter for launching.
8. Launch/drive bridge into water.
9. Connect bridge.
10. Recover bridge.
11. Disassemble bridge.

ENGINEERING--OBSTACLE REMOVAL/BREACHMENT

1. Acquire obstacle to be dealt with.
2. Prepare system hardware for obstacle removal/breaching. The nature of this preparation is entirely dependent upon the sort of system under consideration. It may involve preparation for bulldozing, gun firing, demolition, etc.
3. Decide on placement of fire, charge, or pressure in relation to obstacle.
4. Remove/breach obstacle.
5. Remove/displace remains of obstacle.

OPERATIONS TASKS

ESCAPE FROM SYSTEM

1. Destroy or alter critical components of communication and other sensitive equipment/ documents.
2. Take personal weapon, ammunition, and survival equipment.
3. Position system for escape, if possible under the conditions imposed.
4. Open escape path out of system.
5. Escape from system.

ESTABLISHMENT AND MAINTENANCE OF COMMUNICATIONS

1. Assemble communications device(s).
2. Assemble/erect/orient antenna.
3. Establish communications net.
4. Enter communications net.
5. Transmit messages.
6. Receive messages.

INFORMATION ROUTING

1. Identify appropriate recipients of information.
2. Prioritize recipients for the delivery of information.
3. Prioritize pieces of information for delivery.
4. Assign security classification and method for maintaining that classification.
5. Determine call signals/ frequencies.

LOGISTICS

1. Maintain information on current status of supplies.
2. Maintain information on maintenance status of equipment needed for mission.

LOGISTICS (Continued)

3. Recommend location of rear boundary bases.
4. Recommend main and secondary supply routes.
5. Determine throughout unit supply requirements.
6. Recommend movements which are consistent with logistics considerations.
7. Develop policies for area damage control operations.

NAVIGATION

1. Select appropriate maps and/ or navigation aids.
2. Identify present location.
3. Identify destination.
4. Select travel route.
5. Estimate time of arrival and fuel requirements.
6. Travel designated route.
7. Identify position or route at specified times/locations.

PERSONNEL PLANNING

1. Prepare personnel estimate based on requirements of operation.
2. Estimate casualty rates of friendly forces and projected POW's.
3. Prepare evacuation contingency plans.
4. Coordinate personnel replacement plans with appropriate organizations.

PREVENTION OF DETECTION/LOCATION OF SYSTEM

1. Detect threat warning(s) which indicate either search or attack modes.

OPERATIONS TASKS

PREVENTION OF DETECTION/LOCATION OF SYSTEM (Continued)

2. Identify the nature of the threat(s) from which detected threat warnings emanate.
3. Take appropriate countermeasures to reduce the probability of identification of location. (These countermeasures include: jamming, smoke, flares, chaff, powered decoys, signature alteration, and electronic attack of threat-sensing equipment.)
4. Camouflage system. (System camouflage includes: physical, infrared, and radar signature reduction.)

PREVENTION OF INTERCEPTION/JAMMING

1. Encode messages.
2. Authenticate transmissions.
3. Decode messages.
4. Apply anti-jamming procedures.
5. Apply transmission security procedures.

PROJECTION OF BATTLEFIELD OPERATIONS

1. Determine observable indicators of possible changes in the operational situation.
2. Prioritize indicators of operational changes.
3. Assign intelligence collection tasks to maximize receipt of indicators according to their priorities.

PROJECTION OF BATTLEFIELD OPERATIONS (Continued)

4. Monitor intelligence collection and reassign tasks based on updated information.
5. Display pertinent information.
6. Identify important missing information.
7. Identify important information which is internally inconsistent or probably inaccurate.
8. Develop alternate sources of information.
9. Determine which model(s) of expected enemy behavior best fits collected information.
10. Assign confidence levels to the projection(s).
11. Make recommendations about the effects of projected operations.
12. Prioritize information according to user(s) need and probability of accuracy.
13. Prioritize list of information users for receipt of information based on their functions in this specific operation and their requirements.

PROJECTION OF WEATHER CONDITIONS

1. Collect relevant weather information for the applicable area(s).
2. Develop alternative weather projections and their indicators.
3. Assign probabilities to weather projections.
4. Determine effects of alternate weather projections on operation(s).

OPERATIONS TASKS

PROJECTION OF WEATHER CONDITIONS (Continued)

5. Prioritize indicators of weather projections.
6. Assign weather indicator collection tasks.
7. Monitor weather indicator collection and reassign tasks based on updated information.
8. Update projection probabilities.
9. Collect, order and display pertinent information.
10. Identify important missing information.
11. Identify important information which is internally inconsistent or probably inaccurate.
12. Develop alternate sources of information.
13. Prioritize information according to users' needs and probability of accuracy.
14. Prioritize lists of information users for receipt of information based on their functions in this specific operation and their requirements.

RECONNAISSANCE/FIRE CONTROL

1. Determine target type/number/size/direction/speed/elevation.
2. Determine weather conditions affecting weapons delivery.
3. Determine target coordinates.
4. Mark target locations; this may be done by physical, chemical, radiological or electronic means.
5. Handoff target(s) to attack units.
6. Determine effects of fire on target.
7. Relocate target(s).

RECONNAISSANCE/FIRE CONTROL (Continued)

8. Adjust fire of attacking unit(s).

REPRESENTATION OF FORCES' STATUS

1. Indicate location(s) of forces.
2. Indicate composition (number and type) of forces.
3. Indicate availability of forces.
4. Indicate peculiarities/weaknesses of forces.
5. Indicate recent significant tactical events in which specific units were involved.
6. Indicate actions which forces are currently pursuing. (Your consideration of these actions should include: direction of movement, speed of movement, and apparent purpose(s) of movement.)
7. Indicate the enemy commander's previous behavior in similar situations.
8. Indicate combat effectiveness of forces.
9. Indicate relative combat power of enemy to friendly units.
10. Indicate relevant threat potentials of enemy forces.
11. Identify important missing information.
12. Identify important information which is internally inconsistent or probably inaccurate.
13. Develop alternate sources of information.

OPERATIONS TASKS

PROJECTION OF WEATHER CONDITIONS (Continued)

5. Prioritize indicators of weather projections.
6. Assign weather indicator collection tasks.
7. Monitor weather indicator collection and reassign tasks based on updated information.
8. Update projection probabilities.
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SELECT THE MOST APPROPRIATE FRIENDLY UNIT(S) TO ENGAGE IN OPERATION (Continued)

2. Order these requirements based on commander's priorities.
3. Identify friendly unit(s) with the appropriate mix of attributes to match the prioritized requirements.
4. Determine which friendly units, with the correct attributes, can be removed from their present operations without unacceptable consequences.
5. Determine the transportation systems required to move each friendly unit to the operational area.
6. Determine the availability of each transportation system required to move each friendly unit and the time required for it to perform its function.
7. Determine the logistics required by each friendly unit to perform its functions in the operation in question.
8. Determine the availability of the supplies and delivery systems to the operations area for the required logistics of each friendly unit.
9. Display all significant information and order it in some logical and helpful manner.

SELECTION AND ORDERING OF APPROPRIATE TARGETS

1. Locate potential targets.
2. Identify type and number of potential targets.
3. Determine threat potentials of targets.

SELECTION AND ORDERING OF APPROPRIATE TARGETS (Continued)

4. Determine availability of appropriate friendly weapon system.
5. Determine the probability of eliminating target(s).
6. Prioritize targets.
7. Select targets to attack.

SELF-RECOVERY

1. Prepare system for self-recovery.
2. Reconnoiter for appropriate anchor points and recovery path.
3. Position anchors.
4. Attach cables to anchors/winches.
5. Pull system to safe area.
6. Disassemble/stow self-recovery components.

SYSTEM PROTECTION FROM THREAT

1. Identify threat to system (e.g., onboard fire, flooding, imminent crash, NBC, enemy attack).
2. Activate hardware protective device(s).
3. Put on protective gear/clothing.
4. Secure material/cargo for protection against threat.
5. Assume protective position for crew/passengers.
6. Maneuver to protect from threat.
7. Deactivate hardware protective device(s).

SELECT THE MOST APPROPRIATE FRIENDLY UNIT(S) TO ENGAGE IN OPERATION (Continued)

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OPERATIONS TASKS

TARGET INFORMATION GATHERING AND INTERPRETATION (Continued)

7. Identify target.
8. Determine number of targets.
9. Determine target location/ range.
10. Determine target speed.
11. Determine target direction.
12. Determine target formation/ tactical situation.
13. Select and order targets based on the matching of priorities with target information gathered.
14. Recognize countermeasures and take appropriate action.

VEHICLE MANEUVERING--GROUND VEHICLES

1. Observe environment for obstacles, landmarks, etc.
2. Read and use instruments appropriate to vehicle maneuvering.
3. Perform the following, moving backward (B) and/or forward (f). Circle B or F as appropriate.

3.1	Tight turn.	B	F
3.2	Wide turn.	B	F
3.3	Accelerating turn.	B	F
3.4	Decelerating turn.	B	F
3.5	Rapid acceleration.	B	F
3.6	Gradual acceleration.	B	F
3.7	Rapid deceleration (no stop).	B	F
3.8	Gradual deceleration.	B	F
3.9	Sudden stop.	B	F
3.10	Maintain constant speed.	B	F

VEHICLE MANEUVERING--HELICOPTERS

1. Perform takeoff to hover.
2. Perform instrument takeoff.
3. Perform hover checks.
4. Perform hovering turns.

VEHICLE MANEUVERING--HELICOPTERS (Continued)

5. Perform hovering flight.
6. Perform normal takeoff.
7. Perform maximum performance takeoff.
8. Perform straight and level flight.
9. Perform climbs and descents.
10. Perform turns.
11. Perform instrument turns.
12. Perform acceleration/deceleration.
13. Perform traffic pattern flight.
14. Perform high speed flight.
15. Perform hovering autorotation.
16. Perform standard autorotation.
17. Perform standard autorotation with turn.
18. Perform holding procedures.
19. Perform unusual attitude recovery.
20. Perform before-landing check.
21. Perform shallow approach to a running landing.
22. Perform landing from hover.
23. Perform normal landing approach.
24. Perform shallow landing approach.
25. Perform steep landing approach.
26. Perform instrument approach.
27. Perform GCA approach.
28. Perform IFR helicopter recovery procedure.
29. Perform tactical instrument approach.
30. Perform go-around.

VEHICLE LOADING/UNLOADING

1. Load and position cargo/ passengers in/on vehicle.

OPERATIONS TASKS

TARGET INFORMATION GATHERING AND INTERPRETATION (Continued)

7. Identify target.
8. Determine number of targets.
9. Determine target location/range.
10. Determine target speed.
11. Determine target direction.
12. Determine target formation/tactical situation.
13. Select and order targets based on the matching of priorities with target information gathered.
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3.3	Accelerating turn.	B	F
3.4	Decelerating turn.	B	F
3.5	Rapid acceleration.	B	F
3.6	Gradual acceleration.	B	F
3.7	Rapid deceleration (no stop).	B	F
3.8	Gradual deceleration.	B	F
3.9	Sudden stop.	B	F
3.10	Maintain constant speed.	B	F

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30. Perform go-around.

VEHICLE LOADING/UNLOADING

1. Load and position cargo/passengers in/on vehicle.

OPERATIONS TASKS

WEAPON DELIVERY--MINES

1. Select appropriate location for mine installation.
2. Inspect mine/triggering device/ fusing device.
3. Transport mine.
4. Prepare mine for installation.
5. Install mine (including the digging of a hole).
6. Camouflage mine/triggering device.
7. Aim mine, if applicable.
8. Test circuit(s).
9. Arm mine.
10. Fire mine, if applicable.
11. Disarm mine.

WEAPON FUNCTION MANAGEMENT

1. Determine type of target.
2. Determine speed/direction of target.
3. Determine target range at time of weapon delivery.
4. Determine weather conditions which impact weapon delivery and adjust for them.
5. Determine type of ammunition to be used based on all above factors.
6. Determine probable amount of ammunition required to kill target under existing/projected conditions.
7. Recommend action based on available supply of ammunition, future probable requirements for ammunition, and probable required amount to kill target at various ranges/speeds.

OPERATIONS TASKS

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MAINTENANCE TASKS

For each system function there are maintenance tasks. Maintenance tasks are performed by system operators and maintainers and are categorized as scheduled and unscheduled. Maintenance tasks consist of an action attached to an appropriate object. For each system function the following action segments of maintenance task templates should be used to state the appropriate maintenance tasks.

1. Inspect ______________________________
2. Lubricate ______________________________
3. Fill ______________________________
4. Drain ______________________________
5. Purge ______________________________
6. Paint ______________________________
7. Clean ______________________________
8. Change/Replace ______________________________
9. Troubleshoot/Diagnose ______________________________
10. Remove ______________________________
11. Dissassemble ______________________________
12. Assemble ______________________________
13. Install ______________________________
14. Adjust/Align ______________________________
15. Test ______________________________

CONDITIONS

OPERATIONAL: CREW

1. With optimum crew (specify).
2. With normal operational crew (specify).
3. With minimum crew (specify).

OPERATIONAL: HARDWARE

1. With hardware fully operational.
2. With partial breakdown (specify).
3. With hardware fully down.

OPERATIONAL: INFORMATION INPUTS

1. With full information inputs.
2. With partial information inputs (specify).
3. With no information inputs.

PERSONNEL: APTITUDES

1. With personnel with minimum applicable aptitudes (specify).
2. With personnel with normal applicable aptitudes (specify).
3. With personnel with optimum applicable aptitudes (specify).

PERSONNEL: DURATION OF PRECEEDING WORK

1. Following no work.
2. Following an extended period of work (specify).
3. Following a normal period of work (specify).

PERSONNEL: EXPERIENCE

1. With personnel with minimum experience (specify).
2. With personnel with normal experience (specify).

PERSONNEL: EXPERIENCE (Continued)

3. With personnel with optimum experience (specify).

PERSONNEL: PERCEPTUAL ABILITY

1. With personnel with minimal perceptual abilities (specify).
2. With personnel with normal perceptual abilities (specify).
3. With personnel with optimum perceptual abilities (specify).

PERSONNEL: PHYSICAL SIZE

1. With personnel of minimum size (specify).
2. With personnel of normal size (specify).
3. With personnel of maximum size (specify).

PERSONNEL: PHYSICAL STRENGTH

1. With personnel with minimum strength.
2. With personnel with normal strength.
3. With personnel with optimum strength.

PERSONNEL: PROTECTIVE GEAR

1. While wearing applicable protective clothing/gear (specify).
2. While wearing normal clothing/gear (specify).

CONDITIONS

OPERATIONAL: CREW

1. With optimum crew (specify).
2. With normal operational crew (specify).
3. With minimum crew (specify).

OPERATIONAL: HARDWARE

1. With hardware fully operational.
2. With partial breakdown (specify).
3. With hardware fully down.

OPERATIONAL: INFORMATION INPUTS

1. With full information inputs.
2. With partial information inputs (specify).
3. With no information inputs.

PERSONNEL: APTITUDES

1. With personnel with minimum applicable aptitudes (specify).
2. With personnel with normal applicable aptitudes (specify).
3. With personnel with optimum applicable aptitudes (specify).

PERSONNEL: DURATION OF PRECEEDING WORK

1. Following no work.
2. Following an extended period of work (specify).
3. Following a normal period of work (specify).

PERSONNEL: EXPERIENCE

1. With personnel with minimum experience (specify).
2. With personnel with normal experience (specify).

PERSONNEL: EXPERIENCE (Continued)

3. With personnel with optimum experience (specify).

PERSONNEL: PERCEPTUAL ABILITY

1. With personnel with minimal perceptual abilities (specify).
2. With personnel with normal perceptual abilities (specify).
3. With personnel with optimum perceptual abilities (specify).

PERSONNEL: PHYSICAL SIZE

1. With personnel of minimum size (specify).
2. With personnel of normal size (specify).
3. With personnel of maximum size (specify).

PERSONNEL: PHYSICAL STRENGTH

1. With personnel with minimum strength.
2. With personnel with normal strength.
3. With personnel with optimum strength.

PERSONNEL: PROTECTIVE GEAR

1. While wearing applicable protective clothing/gear (specify).
2. While wearing normal clothing/gear (specify).

CONDITIONS

TARGET: DIRECTION OF MOTION

1. Closing (specify angle).
2. Retreating (specify angle).
3. Crossing (specify direction).
4. Complex maneuver (specify).

TARGET: LOCATION

1. Minimum range (specify).
2. Maximum range (specify).
3. Normal range (specify).
4. Azimuth and elevation of target (specify).

TARGET: NUMBER

1. Single target.
2. Multiple simultaneous targets (specify).
3. Multiple sequential targets (specify).
4. Combination of multiple simultaneous and multiple sequential targets (specify).
5. Noise - number/% of targets within nontarget background (specify).

TARGET: TYPE

1. Specify by type or size.

TARGET: SPEED

1. Maximum speed (specify).
2. Minimum speed (specify).
3. Cruising speed (specify).
4. Radical alterations of speed (specify).
5. Stationary.

TERRAIN: GROUND SLOPE

1. Flat.
2. Low positive hilly (specify).
3. Low negative hilly (specify).
4. High positive mountainous (specify).
5. High negative mountainous (specify).

TERRAIN: GROUND SURFACE

1. Sandy.
2. Rocky.
3. Loam (deep soil).
4. Paved (specify type and carrying level).
5. Broken paved.
6. Broken ground.
7. Plowed fields.
8. Bare packed.
9. Vegetation covered.

TERRAIN: GROUND AND WATER SURFACE

1. Light mud.
2. Heavy mud.
3. Dry.
4. Water covered.
5. Ice covered.
6. Snow covered.

TERRAIN: OBSTACLES

1. Dense vegetation.
2. Light vegetation.
3. Hedge rows.
4. Rivers (specify depth, width).
5. Manmade structures (specify).
6. Traps (specify).
7. No obstacles.

CONDITIONS

TARGET: DIRECTION OF MOTION

1. Closing (specify angle).
2. Retreating (specify angle).
3. Crossing (specify direction).
4. Complex maneuver (specify).

TARGET: LOCATION

1. Minimum range (specify).
2. Maximum range (specify).
3. Normal range (specify).
4. Azimuth and elevation of target (specify).

TARGET: NUMBER

1. Single target.
2. Multiple simultaneous targets (specify).
3. Multiple sequential targets (specify).
4. Combination of multiple simultaneous and multiple sequential targets (specify).
5. Noise - number/% of targets within nontarget background (specify).

TARGET: TYPE

1. Specify by type or size.

TARGET: SPEED

1. Maximum speed (specify).
2. Minimum speed (specify).
3. Cruising speed (specify).
4. Radical alterations of speed (specify).
5. Stationary.

TERRAIN: GROUND SLOPE

1. Flat.
2. Low positive hilly (specify).
3. Low negative hilly (specify).
4. High positive mountainous (specify).
5. High negative mountainous (specify).

TERRAIN: GROUND SURFACE

1. Sandy.
2. Rocky.
3. Loam (deep soil).
4. Paved (specify type and carrying level).
5. Broken paved.
6. Broken ground.
7. Plowed fields.
8. Bare packed.
9. Vegetation covered.

TERRAIN: GROUND AND WATER SURFACE

1. Light mud.
2. Heavy mud.
3. Dry.
4. Water covered.
5. Ice covered.
6. Snow covered.

TERRAIN: OBSTACLES

1. Dense vegetation.
2. Light vegetation.
3. Hedge rows.
4. Rivers (specify depth, width).
5. Manmade structures (specify).
6. Traps (specify).
7. No obstacles.

MAINTENANCE TASKS

For each system function there are maintenance tasks. Maintenance tasks are performed by system operators and maintainers and are categorized as scheduled and unscheduled. Maintenance tasks consist of an action attached to an appropriate object. For each system function the following action segments of maintenance task templates should be used to state the appropriate maintenance tasks.

1. Inspect ______________________________
2. Lubricate ______________________________
3. Fill ______________________________
4. Drain ______________________________
5. Purge ______________________________
6. Paint ______________________________
7. Clean ______________________________
8. Change/Replace ______________________________
9. Troubleshoot/Diagnose ______________________________
10. Remove ______________________________
11. Dissassemble ______________________________
12. Assemble ______________________________
13. Install ______________________________
14. Adjust/Align ______________________________
15. Test ______________________________

APPENDIX B

EXCERPTS FROM A TEST AND EVALUATION MASTER PLAN (TEMP)

APPENDIX B

EXCERPTS FROM A TEST AND EVALUATION MASTER PLAN (TEMP)

Part I. Description

A. Mission

1. Heavy division, separate armored/mechanized brigade and armored cavalry regiment HIP battalions are organized, manned and equipped to perform the Direct Support mission as well as the other Field Artillery standard tactical missions of Reinforcing, General Support Reinforcing, General Support and nonstandard tactical missions. Other HIP equipped battalions can perform all standard tactical missions except Direct Support without augmentation.

2. HIP battalions will predominantly provide close support fires against targets posing a threat to the committed brigades. Additionally, close support fires will be provided for rear area combat operations, and long range fires will be used to augment other fire support systems in attacking threat forces before they can influence the battle. The HIP will fire both conventional and nuclear munitions and will be compatible with all fielded and developmental 155mm munitions and propelling charges. HIP type units will also be in Corps Artillery where they will augment the fires of divisional/brigade field artillery units.

3. The HIP must be capable of worldwide deployment with heavy US forces, and suitable for the most extreme rigors of land combat in the 1990-2010 timeframe. The most severe test of US Army capabilities is expected to continue to be one of opposing Warsaw Pact invasion of Germany. Combat there would be dominated by highly mobile, heavily armored maneuver forces supported by massive amounts of cannon and rocket artillery and close support aircraft. In the opening phases of combat the threat would use both conventional and toxic chemical and possibly biological weapons, as the Warsaw Pact attacks behind the Forward Line of Troops and concentrates on the destruction of US/NATO nuclear capability in preparation for the nuclear phase of the conflict. The Warsaw Pact forces would be numerically superior to the US/NATO forces, with near technological parity. Force ratios would drive the direct fire fight in their favor if effective fire support were not available.

4. The HIP must possess sufficient mobility to accompany its supported maneuver forces, and be available in sufficient numbers to provide responsive, effective fires throughout the supported commander's area of influence. The Warsaw Pact forces will be attempting to find and destroy the HIP as one of the highest priorities in the breakthrough zone.

5. The Heavy Brigade/Division Field Artillery Fire Support Weapon System Mission Element Need Statement (MENS), approved in Dec 80, identified four major deficient areas in the current Division Support Weapon System:

a. Responsiveness: the ability to rapidly deliver and sustain massed firepower on the target.

b. Survivability: the ability of the weapon system, its ammunition and crew to withstand counterfire, mines, electromagnetic effects, and air, ground, and nuclear, biological, and chemical (NBC) attack. This includes operations in a contaminated area and in areas subjected to Nuclear Weapons Effects (NWE).

c. Terminal Effects: the ability to achieve the desired attack criteria (destruction/neutralization/suppression) against enemy elements in the full spectrum of battlefield environments.

d. Reliability, Availability, Maintainability and Durability RAM-D): the operational performance of the weapon system in terms of failure rates, time required for repairs, and maintenance downtime.

6. The DSWS SSG has analyzed M109A2/A3/A3E1 deficiencies and has determined the functional characteristics of HIP required to remedy these deficiencies. Command reviews have prioritized these characteristics for a mid-term interim system, which have been set forth in the LOA for HIP.

B. System. The HIP consists of a 155mm Self-Propelled Howitzer (SPH), its Integrated Logistics Support (ILS), and command, control and communications (C^3) interface with the artillery fire support system. The SPH is a product improvement of the M109A2/A3.

1. System Description.

a. Self-Propelled Howitzer (SPH):

(1) The HIP SPH, designated the M109A3E2, is an armored, fully tracked howitzer carrying 34 complete conventional geometry rounds and two oversized projectiles on board. It is operated by a nominal crew of five, including the driver. Its main armament consists of a modified version of the M185 Cannon Assembly (the XM284) and M178 Gun Mount (the XM182) currently employed on the M109A2/A3/A3E1. All current, as well as developmental, US conventional 155mm artillery projectiles will be system compatible. The cannon, propelling charge, and projectile mix will permit unassisted ranges of at least 22 km and a maximum assisted range of at least 30 km. In addition, as a parallel R&D effort, the VCSA has directed that an armament system consisting of a new 39 caliber cannon (the XM283) and a modular redundant component gun mount (the XM183), and a cannon which extends the range capability beyond 30 km (the XM282) be developed and investigated during HIP.

(2) The fire control system will be fully automated, providing accurate position location and azimuth reference, onboard ballistic solutions of fire missions (with external backup), and computer controlled gun drive through servos with manual backup. These improvements will permit flexibility (emplacement times will be less than 60 seconds) and accommodate high firing rates. The emplaced SPH will be able to fire within 30 seconds. Digital and voice communications utilzing current systems and the Single Channel Ground/Air Radio System (SINCGARS), will enable dispersed operations/missions from one firing unit to multiple battalions. Tactical and technical fire control and

direction will be maintained through an interface with a Battery Computer System (BCS), and Advanced Field Artillery Tactical Data System (AFATDS). The SPH will also fully incorporate state-of-the-art materials and technologies to achieve maximized availability and maintainability through the use of Built-In-Test Equipment (BITE), both diagnostic and prognostic; modularity; redundancy; reduced operating stress levels and enhanced component and ballistic protection for the crew and vital equipment. All product improved equipment will also be hardened to withstand Nuclear Weapons Effects (NWE).

(3) The HIP SPH equipped with the new 39 caliber cannon and new gun mount is designated the M109A3E3 howitzer.

b. Interface with Fire Support: The HIP will have the capability to interact with the command, control, and communication of the artillery fire support system. It shall be able to communicate with the fire support element, whether it is a battlion/brigade fire support section (FSS), battalion Operations/Intelligence Section, target acquisition (e.g., ATHS, FIREFINDER, RPV, FIST, FO) or a battalion or platoon fire direction center, using AFATDS, BCS, and SINCGARS communication equipment.

2. Interfaces. The HIP must be compatible with:

a. Ammunition: All US standard and developmental 155mm ammunition, to include fuzes, projectiles, propelling charges, primers (except MK2A4), and their packaging.

b. C^3 Elements: SINCGARS Communication Equipment, AFATDS, ATHS, BCS, FIREFINDER, RPV, FIST DMD, and FO DMD.

c. Integrated Logistics Support (ILS) Elements: Design influence and integration to include logistic related reliability and maintainability; maintenance plan; supply support; support equipment and TMDE to include Built-In Test (BIT)/Built-In Test Equipment (BITE); technical data; computer resources support; packaging, handling and storage; transportation and transportability; facilities; standardization and interoperability; and MANPRINT to include manpower and personnel, training and training devices, and safety, health and human factors.

d. Ammunition Resupply Vehicle: M992 FAASV and M548 ARV.

C. Required Operational Characteristics. The HIP required operational characteristics are addressed in the HIP Letter of Agreement and in the HIP Operational and Organizational (O&O) Plan. The HIP has the traditional artillery characteristics of shoot, move, communicate, and survive, but does them in such an effective manner so as to optimize responsiveness, terminal effects, survivability, and reliability, availability and maintainability (RAM); thus increasing the combat multiplier by giving the effect of having more cannons on the battlefield. Required operational characteristics are reflected in the criteria of Part I, Paragraph E. of this TEMP.

D. Required Technical Characteristics. Most HIP required technical characteristics are expressed in terms of operational performance thresholds and are listed in the HIP System Specification. Subordinate technical characteristics not so expressed will be derived by the development contractor using the system engineering process.

E. HIP Issues and Criteria. The following Issues and Criteria have been developed by the TRADOC System Manager - Cannon for the M109 155mm SP HIP. After staffing with the agencies specified in TRADOC Reg 71-9 they will be presented to the TRADOC Materiel Evaluation Committee's Senior Advisory Council for approval prior to submission to AMC and HQ, DA. Those issues that are considered critical and must be addressed before proceeding from one phase of development to the next are denoted by an asterisk. The criteria below reflect requirements based upon analysis of SCORES Europe I, Sequence IIA; modifications to certain of these criteria may be necessary when analysis of SCORES Europe V is complete. As independent evaluation plans are developed, a data source matrix will be finalized. OT II will confirm that the HIP battalion's operational concept can be executed by representative soldiers using prototype equipment while in a tactical environment based on the SCORES, Europe V scenario. The test unit will employ the HIP O&O Plan under the conditions specified in the Operational Mode Summary/Mission Profile (OMS/MP). DT II will demonstrate that developmental engineering objectives required to support operational objectives are met. The criteria below apply when the HIP howitzer is equipped with the modified M185/M178 armament package (M109A3E2) and is operational. Modifications and changes to the criteria when the HIP howitzer is equipped with an alternative armament package (M109A3E3) are contained in Annex B. RAM failures will be scored IAW the procedures specified in the RAM Annex of the HIP LOA.

1. Mission Performance.

a. *Issue 1.
Is the fire support provided by the HIP howitzer responsive?

(1) Scope. The tactical scenario will require the HIP howitzers, and crews, to provide fire support for maneuver forces IAW the conditions specified in the OMS/MP for twenty-four hour wartime weighted average periods. The howitzer and crews' capability for firing while emplaced and for responding to calls for fire while moving will be evaluated. Operations will be conducted in varied terrain conditions. The HIP howitzer will be employed in both open and closed configurations and in its backup, manual mode of operations for emplacement, lay and firing. The HIP howitzer will respond to calls for fire from target acquisition sources as well as fire commands/orders from fire direction centers. These capabilities will be evaluated during periods of reduced visibility (day and night) and while the crew is in various NBC mission-oriented protective postures (MOPP), up to and including MOPP IV. Normally the ammunition fired will be stowed on-board the howitzer in an unpackaged, ready configuration (projectiles fuzed in ammunition racks, propelling charges stored in their packing containers).

(2) Criteria.

(a) Upon receiving a call for fire from a FA target acquisition source (fire-for-effect missions only) or fire commands from a fire direction center, the median time for an emplaced HIP howitzer to fire the initial round of the mission must be less than 30 seconds (45 seconds for high angle missions).

(b) Upon receiving a fire mission from an FA target acquisition source (fire-for-effect missions only) or fire commands from a fire direction center, the median time for a moving HIP howitzer to stop and fire the initial round of the mission must be less than 60 seconds (75 seconds for high angle missions).

(c) An emplaced HIP howitzer must demonstrate the capability to fire one oversized projectile (e.g., 54 inch Copperhead round) in a median time of less than 40 seconds after receiving fire commands.

(d) When emplacing, laying, and firing in its backup, manual mode of operations, the HIP howitzer crew must equal or exceed the standards for the M109A2/A3 prescribed in ARTEP 6-100.

(3) Rationale. To respond to the maneuver forces' demands for close, continuous, and effective fire support, HIP howitzer units must demonstrate their capabilities for emplacing and rapidly firing one or more fire missions.

(4) Source. Letter of Agreement (LOA), para. 3c(3), 3d(1), 3e(1); ARTEP 6-100, The Field Artillery Cannon Battery.

b. *Issue 2. Is the firepower provided by the HIP howitzer effective?

(1) Scope. The tactical scenario will stress the howitzer and crews' capability for providing the volume of fire required during operations conducted IAW the OMS/MP twenty-four hour wartime weighted-average periods. The SCORES Europe I, Sequence IIA OMS weighted average for firepower is equivalent to 73 missions and 301 rounds per howitzer per day. The rate of fire achieved using the mechanical loader assist (if included as part of HIP modifications) will be compared with the rate of fire achieved in the manual-loading mode and with the rate of fire of the M109A3E1 (HELP) howitzer. Ammunition fired for rate-of-fire testing normally will be stowed on board the howitzer in an unpackaged, ready configuration (projectiles fuzed in ammo racks, propelling charges stored in their packing containers). The sustained rate of fire for a HIP howitzer employed with an FA ammunition support vehicle (FAASV) and with the M548 will be evaluated. The accuracy of the automated on board position location system, gun pointing (gun drive servos) and technical fire control systems will be recorded and reported. The rate of fire for high-angle missions may be reduced by the time required to elevate the cannon above the maximum loading elevation (TBD by DT testing). Data on firing accuracies measured at the point of impact will be collected and reported. These capabilities will be evaluated during periods of reduced visibility, under varied terrain conditions, during day and night operations, and in various NBC mission-oriented protective postures, up to and including MOPP IV.

(2) Criteria.

(a) The HIP howitzer (in a fully operational status) and crew must be capable of firing 301 rounds per tube per day.

(b) The HIP howitzer and crew must equal or exceed a maximum firing rate of 6 rounds per minute for low-angle fire, if the howitzer is equipped with a mechanical loader assist; otherwise, four rounds per minute for low-angle fire.

(c) The firing accuracy of the HIP howitzer fire control system must equal or exceed the accuracy achieved by the M109A2/A3 fire control system.

(d) The precision probable error in range for the howitzer's armament system when firing unassisted projectiles will be 0.25% of range and for assisted projectiles 0.30% of range. The precision probable error in deflection will be 1 mil.

(e) The howitzer's armament system will achieve an unassisted maximum range of greater than or equal to 22 km, an assisted maximum range of greater than or equal to 30 km, and a minimum range for high-angle fire of less than or equal to 4 km.

(f) The on-board ballistic computer solutions and the BRL standard (BCS) solutions must compare to within 0.05% of range or 5 meters, whichever is greater.

(3) Rationale. The required volume of firepower is specified in the HIP operational mode summary/mission profile and is dependent upon the howitzer being fully operational. If the howitzer is equipped with a mechanical loader assist, the increased rate of fire will enable the howitzer to provide the required firepower and creates the effect of having additional tubes on the battlefield. Measurement of fire mission accuracy standards in an operational environment are explained in ARTEP 6-100, The Field Artillery Cannon Battery. Increasing the howitzer's assisted range to 30+ km will enable the HIP to attack the majority (approximately 95% per FA Simulation Two-Sided (FAST) analysis) of the targets available.

(4) Source. LOA, para 3d(1), (3), (5), and 3e(1); Annex A, para 4f(4)(b); ARTEP 6-100, Appendix E. Precision requirements, USAFAS, BRL.

c. *Issue 3. Is the HIP howitzer's external and internal command, control, and communications system effective?

(1) Scope. The capabilities of the howitzer's internal and external communications systems for providing digital and voice communications during tactical operations will be evaluated. The tactical scenario will be based on the SCORES, Europe V scenario and will stress the unit's command, control, and communications capability for operating the HIP howitzer during

twenty-four hour, OMS/MP wartime weighted-average periods. Fire missions will be conducted primarily on digital nets. Command and Control and administrative/logistical communications will be conducted primarily on the voice net. The howitzer's voice radio and wire backup capabilities will be evaluated. Operations will be conducted in varied terrain conditions, during day and night operations, in various NBC mission-oriented protected postures, up to and including MOPP IV. The test will be conducted in a hostile EM/EW environment including active ECM, representative of the anticipated threat and countermeasures. The howitzer will operate in an automated mode, using the on-board processor for ballistic computations (FFE missions), mission storage, armament position/direction, safety, firing, (commands and data) fuze setting (if included as part of HIP modifications), message traffic, and on-board diagnostics/prognostics. The evaluation of the utility of the on-board processor for improving command and control of the HIP howitzer is investigative in nature. The unit's capability for operating in a degraded C^3 mode will be evaluated and is investigative in nature.

(2) Criteria.

(a) The HIP howitzer must receive and transmit the density of communications/message traffic, under conditions and over distances required by the approved OT tactical scenario.

(b) The HIP howitzer's external communications system must communicate via voice or digital radio, with the nodes specified in the O&O Plan (including ATHS, AFATDS, BCS, FIST DMD, FO DMD, Q36, Q37, RPV (ground station)) under conditions, and over distances required by the approved OT tactical scenario.

(c) When the howitzer's voice and digital communications systems are inoperable the HIP howitzer must communicate by wire with other howitzers and the platoon FDC over distances of at least 100 meters.

(d) The howitzer's internal communications system must transmit and receive at each on board station.

(3) Rationale. An effective external and internal communications system will enable the HIP howitzer to provide responsive and effective fire support while executing semi-autonomous (dispersed positioning) operations. A backup capability is required for continuous operations when voice and digital communications are degraded to unacceptable levels.

(4) Source. O&O Plan, Chapter 4; LOA, Para. 3c(4), (6), 3e(1); LOA/Annex A, Para. 4f; ARTEP 6-100. ARDC Training Manual TS-85-1.

d. Issue 4. Is the HIP howitzer's mobility/transportability adequate?

(1) Scope. A combat-loaded HIP howitzer's capability for meeting the mobility requirements specified in the OMS/MP will be evaluated. Frequent emplacements, displacements and road marches are required to provide continuous fire support for the maneuver forces. The operational scenario

will be based on twenty-four hour OMS/MP wartime weighted-average periods. The utility of the howitzer's day/night vision devices will be evaluated and recorded. Day and night operations will be conducted in both opened and closed vehicle configurations, while traveling cross-country and on primary and secondary roads, under varied terrain conditions. The assessment of howitzer mobility will include an analysis using the TACOM NATO Reference Mobility Model. An analytical assessment of the ability of the HIP howitzer to meet applicable air, rail, bridge, and tunnel restrictions is required. The HIP howitzer's capability for being tactically loaded, off-loaded and prepared for action by representative soldiers using TOE equipment and tie-down devices on road, rail, sea, and air carriers will be evaluated.

(2) Criteria.

(a) Combat-loaded HIP howitzers in a fully operational status must meet the mobility requirements specified for the OMS/MP twenty-four hour wartime-weighted average; 10 moves totaling 22 km.

(b) The HIP howitzer must provide the vehicle driver the day/night vision capability to conduct tactical operations in a closed vehicle configuration.

(c) Combat-loaded HIP howitzers must achieve the following speeds while operating in a tactical environment.

Primary Roads:	55 KPH/34 MPH (Maximum)
Primary Roads:	35 KPH/22 MPH (Average)
Secondary Roads:	25 KPH/15 MPH (Average)
Cross Country:	20 KPH/12 MPH (V-80 dry conditions using TACOM's NATO Reference Model)

(d) The HIP howitzer must be as transportable as the M109E4, 155mm self-propelled howitzer by road, rail, sea and air (C5A) (AR70-44 applies). The HIP howitzer must meet European rail, bridge, and tunnel restrictions. MIL-STD-209, 810 and 1366 (Envelopes A and B) will apply.

(e) The howitzer crew, using the required tools and equipment must demonstrate the capability to load, secure, off-load, and prepare the HIP howitzer for action in times equivalent to those required for the M109A2/A3.

(f) Lifting and tie down procedures for the HIP howitzer will meet the specificatons of MIL-STD-209.

(g) Combat-loaded HIP howitzers must achieve a cruising range of at least 300 km when traveling on primary roads at 35 kph/22 mph.

(h) Combat-loaded HIP howitzers must achieve a fording depth of at least 42 inches (1.07 meters).

(3) Rationale. To enable HIP units to provide close and continuous fire support, the HIP howitzer's speeds must be equivalent to the M109A2/A3. Frequent emplacements, displacements, and road marches, as specified in the OMS/MP, are required. The HIP howitzer must be as transportable by road, rail, sea, and air (C5A) as the unit that it habitually supports. Howitzer speeds are based on a TACOM cross-country mobility study using the NATO Reference Model.

(4) Source. LOA, Para. 3c(1), (5), 3e(1); LOA/Annex A, Para. 4f; TACOM Mobility Analysis.

2. Survivability/Vulnerability.

a. *Issue 5. Are the HIP howitzer's, crew's, and unit's survivability and vulnerability characteristics adequate?

(1) Scope. Operations will be conducted in simulated NBC contaminated and realistic electronic warfare (including jamming) environments, and when HIP units are faced with the threat of ground and air attacks. Howitzer crews and equipment will be stressed by performing day and night operations, IAW the OMS/MP, while the crew is wearing ventilated facepiece and microcooling equipment in various MOPP conditions, up to and including MOPP IV. Personnel and equipment decontamination procedures will be evaluated. Performance degradation while operating in NBC, NWE, and EW environments will be assessed. This issue requires an evaluation of the capabililties of the on-board electronics and electrical devices for operating while under the adverse conditions caused by electromagnetic effects (including electromagnetic interference and compatibility, RF susceptibility, lightning susceptibility, electrostatic discharge, TEMPEST, high altitude, electromagnetic pulse and nuclear weapons effects) and electronic countermeasures/electronic counter-countermeasures. In addition, the howitzer's and unit's capability for firing direct fire when faced with a ground attack, and making survivability displacements when subjected to enemy counterfire will be evaluated. Testing on a HIP howitzer ballistic hull and turret will be conducted to evaluate the reduction in vulnerability provided to the crew and critical howitzer components by application of the HIP vulnerability improvement kit.

(2) Criteria.

(a) The product improved items integrated into the HIP howitzer will meet the nuclear survivabililty standards derived from QSTAG 244.

(b) The HIP howitzer crew must operate the howitzer for a period of at least 12 hours while in MOPP IV equipment, with an average individual and collective mission-essential task performance degradation of not more than 5 percent as a measure of time (when compared with the initial performance level on the first iteration of the task. Mission-essential tasks include:

1. Prepare howitzer for conduct of fire missions.

2. Execute fire commends.

3. Recover and prepare for movement.

4. Store and transport ammunition.

(c) There must be no more than a negligible risk (5 percent) of heat stress casualties for a HIP howitzer crew in MOPP IV equipment performing mission-essential tasks for a period of at least 12 hours.

(d) A HIP howitzer must be decontaminated by its crew using standard TOE field decontaminants, equipment and procedures in not more than one hour. Standard decontamination procedures will not adversely affect howitzer system functions.

(e) The HIP howitzer's on-board electronics and electrical devices must be operable without degradation when subjected to adverse electromagnetic effects in accordance with MIL-STD-461, -462, -1757, and -331 and MICOM-TR-RT-81-5.

(f) The HIP howitzer must be certified for TEMPEST per NACSIM5100A and NACSEM 5112, Appendix A.

(g) The HIP howitzer and crew must initiate emergency and survivability displacements in less than one minute after being given the order to displace.

(h) The HIP howitzer unit must fire its primary and secondary armament in direct fire IAW the procedures in FM 6-50, and IAW the tasks, conditions and standards of ARTEP 6-100.

(i) Ballistic protection provided to the HIP howitzer will reduce the vulnerability (type TBD) to the crew and selected critical components when compared to protection afforded to the M109A3E1.

(3) Rationale. HIP howitzer units face threats from enemy artillery, NBC munitions, armor, mechanized infantry, aircraft, armed helicopters, electronic warfare, and dismounted special forces. The criteria for NBC survivability are specified in DCSOPS letter, subject: DA Approved Quantitative NBC Contamination Survivability Criteria, 7 February 1985. Procedures for battery defense versus ground and air targets are explained in detail in FM 6-50 and ARTEP 6-100. Emergency displacement times are specified in ARTEP 6-100. Mission-essential howitzer section performance tasks are those mandatory tasks specified in ARTEP 6-100.

(4) Source. LOA, Para. 3a(1), (2), (3), (4), (5), (6). QSTAG 244 standards are specified in USANCA letter, 20 Jan 84, Subject: Nuclear Survivability Criteria for the Howitzer Improvement Program (HIP), AR 70-71.

3. Reliability, Availability, and Maintainability.

a. *Issue 6. Is the operational availability, reliability, and maintainability of the HIP howitzer adequate to ensure that the system will be operationally effective and logistically supportable when fielded?

(1) Scope. The operational availability, reliability, and maintainability of the howitzer will be demonstrated while operating IAW the OMS/MP. Test data will provide an estimate of HIP howitzer durability. Operations will be conducted IAW the conditions specified for twenty-four hour, OMS/MP weighted-average periods during day and night and in varied terrain. Equipment failures will be recorded and reported IAW the procedures specified in the RAM Annex of the HIP LOA. The howitzer will be operated, maintained, and repaired by representative soldiers in a tactical environment. Operational availability is the principal measure of user readiness requirements.

(2) Criteria.

(a) The HIP howitzer must achieve a wartime operational availability (Ao) of at least 0.60 when equipped with a modified M185/M178 armament system.

(b) The HIP howitzer must achieve a Mean Time Between Operational Mission Failures (MTBOMF) of at least 90 hours when equipped with the modified M185/M178 armament system.

(c) The HIP howitzer must achieve a mean time between essential maintenance actions (MTBEMA) of at least 20 hours.

(d) The following minimum acceptable values for maintainability will be attained when equipped with either the modified M185/M178 armament system or the advanced armament system (new 39 caliber cannon and new modular gun mount).

Parameter	MAV
MR/UNIT	0.14
MR/I(DS)-ON	0.099
MR/I(DS)-OFF	0.028
MR/I-GS	0.090

(3) Rationale. The frequency of mission stopping failures and the capability of the support system to repair and return equipment to action are the most significant factors contributing to operational RAM. Assumptions made to support user analysis leading to establishment of the tentative RAM

requirements above include: operation in accordance with the HIP OMS/MP as presented in Annex A of the HIP LOA; the HIP failure definition/scoring criteria; trilevel maintenance support; firing a mix of propelling charges consisting of 4.1% M203, 7.0% M119, 37.1% M4A1 and 51.8% M3A1 (based on results of SCORES Europe I, Sequence IIA analysis); and manpower constrained by Army of Excellence force levels.

(4) Source. LOA, Para. 3b(1) and Annex E.

4. Organization and Operation.

a. Issue 7. Does the HIP battalion's organizational TOE provide the personnel and equipment necessary for the unit to perform semiautonomous operations?

(1) Scope. Tactical operations will be conducted in simulated wartime environment using the SCORES, Europe V scenario. The unit will be stressed during day and night operations, IAW the OMS/MP, in varied terrain conditions, while the crew is in various NBC mission-oriented protective postures up to and including MOPP IV. Operations identified in the O&O Plan will be conducted and the adequacy of the TOE organization for accomplishing the unit's performance of semiautonomous operations while moving, shooting, and communicating in support of the maneuver commander will be assessed. Semiautonomous operations refers to the dispersed positioning of individual howitzers within a one kilometer diameter circle during periods of intense counterfire threats.

(2) Criterion. This issue is investigative in nature.

(3) Rationale. The HIP TOE contains deviations from the current 155mm SP howitzer battalion TOE. An assessment of the HIP organization's adequacy is necessary to ensure that the TOE will support a unit's ability to conduct semiautonomous operations.

(4) Source. Operational and Organizational Plan, Chapter 3.

b. *Issue 8. Are the planned doctrine, tactics, and techniques for HIP units adequate?

(1) Scope. Tactical operations will be conducted in simulated wartime environment using the SCORES, Europe V scenario. The HIP unit will be stressed during day and night operations, IAW the OMS/MP, in varied terrain conditions, and while the crew is in various NBC mission oriented protective postures up to and including MOPP IV. The adequacy of the doctrine, tactics, and techniques for HIP units performing semi-autonomous operations while moving, shooting, and communicating in support of the maneuver force will be assessed. Semiautonomous operation refers to the dispersed positioning of individual howitzers within a one kilometer diameter circle during periods of intense counterfire threats. Testing of the doctrine, tactics, and techniques based upon the HIP O&O concept and tactical SOP. The HIP howitzer will demonstrate the capability to complete to standards 100

percent of the attempted applicable mandatorytasks contained in ARTEP 6-100. Non-mandatory tasks will be selected by the test director based on those tasks that will occur during the exercise scenario. The scoring system will provide a percentage GO/NO GO score in each of the seven battalion mission/tasks. Battalion and battery fire missions will be scored for both time and accuracy IAW the derived HIP ARTEP.

(2) Criteria.

(a) The evaluated battalion/battery must successfully accomplish, as a minimum, 80 percent of the specified battalion/battery live-fire missions and 100 percent of the specified dry-fire missions to HIP ARTEP standards.

(b) The HIP howitzer battalion must achieve a minimum of 80 percent overall "GOs" under the HIP ARTEP Standards, for each of the seven battalion ARTEP tasks: (1) coordinate fire support; (2) acquire targets; (3) deliver field artillery fires; (4) communicate; (5) movement; (6) maintain and resupply; and (7) perform survivability operations.

(c) The HIP unit must successfully accomplish 100 percent of the nuclear tasks required in ARTEP 6-100.

(3) Rationale. The HIP O&O Plan contains significant deviations from current 155mm SP howitzer unit operations. An assessment of HIP doctrine, tactics, and techniques is necessary to ensure that units are capable of conducting semiautonomous operations while providing continuous, responsive, and effective fire support for maneuver forces. Following the scoring system of ARTEP 6-100 will allow the evaluation of a HIP unit's strengths and weaknesses. It also provides a realistic measure of the effectiveness of the HIP provided by the training support package.

(4) Source. HIP O&O; ARTEP 6-100; HIP Tactical SOP.

5. Interoperability.

a. *Issue 9. Does the HIP howitzer unit adequately interface and interoperate with the fire support system?

(1) Scope. The capabilities of the HIP howitzer and its unit's communications equipment will be demonstrated during tactical operations conducted IAW the OMS/MP twenty-four hour, wartime weighted-average to evaluate

the adequacy of their interoperability with the fire support system. The HIP howitzer unit will directly receive fire missions requesting approved 155mm shell/fuze/propellant combinations from field artillery target acquisition sources (including FIREFINDER, the RPV system, FIST, observers, laser teams, and brigade and battalion fire support sections). All fielded US 155mm projectiles, fuzes, primer ignition systems (except the MK2A4 primer), and propelling charges will be fired during the evaluation of the HIP howitzer's modified M185/M178 armament system. An analytical assessment of the HIP howitzer's interoperability with developmental 155mm munitions will be performed. Ammunition transfer operations using field artillery ammunition support vehicles will be conducted. The HIP's standardization program and its commonality with the Army support system will be evaluated during the logistics support assessment review process.

(2) Criteria.

(a) The HIP howitzer must interface and interoperate, through its on-board communications system with the field artillery fire support hardware and software (e.g., BCS, AFATDS) at battalion operations centers, fire support elements (include brigade, battalion and FIST), platoon fire direction centers and target acquisition sources; as specified in the HIP User Interface Requirements (UIR) document and HIP Operational and Organizational Plan.

(b) The HIP modified M185/M178 armament system must fire all fielded and developmental US 155mm projectiles, fuzes, primer ignition systems (except the MK2A4 primer) and propelling charges (except those specifically developed for the advanced armament system and extended range cannon).

(c) The HIP howitzer must interoperate with field artillery ammunition support vehicles, i.e., receive projectiles from a FAASV at the rate of at least four complete rounds per minute, and perform ammunition uploads of 34 complete conventional geometry rounds and 2 Copperhead rounds in a median time of less than 20 minutes in an uncontaminated environment.

(3) Rationale. HIP howitzer units must have digital data and voice communications interfaces with the fire support system to support the maneuver commander. The capability for using all fielded and developmental US 155mm munitions is cost effective and fully uses the existing and planned US inventory, reduces the logistics and training burdens associated with the restricted use of certain munitions combinations, and eliminates the need to develop unique munitions. Commonality between vehicles and commonality with the Army support system reduces the logistics burden and training required to maintain and support the HIP howitzer.

(4) Source. LOA, Para. 3b(3), 3c(6), (7), (8), and 3d(4); User Interface Requirements (UIR).

6. MANPRINT

a. *Issue 10. Is the HIP howitzer safe to operate, maintain, and repair?

(1) Scope. This issue addresses the HIP howitzer and its support equipment's capability for safe crew operation, maintenance, and repair in an operational environment. Hazards identified will be categorized IAW MIL-ST-882. Measurement of the crew's air supply will be taken with and without collective NBC protection equipment, and in open and closed howitzer configurations.

(2) Criteria.

(a) The system will be evaluated to ensure that there are no hazards with a hazard severity/hazard probability rating of IA, B, C, D; IIA, B, C, AND IIIA (Deficiencies), and, if economically feasible, from cost-benefit analysis IID, IIIB, C (Shortcomings). (See attached Hazard Probability versus Severity Chart, Fig. B-1).

(b) Electromagnetic radiation hazards will be controlled IAW TB MED 523.

(c) The HIP howitzer will not expose crew or maintenance personnel to concentrations of toxic substances or gases in excess of the limits specified in the Handbook of American Conference of Government Industrial Hygienists. This includes exposure to HALON 1301, the substance contained in the fixed fire suppression system.

(d) The air supply to the crew shall meet toxicity criteria with respect to combustion products from weapon firing and internal combustion engine, as outlined in MIL-STD-1472 and MIL-HDBK-759.

(e) The electronics and electrical environment of the system will meet the parameters of MIL-STD-454.

(f) The noise profile of the HIP howitzer during all modes of operations will meet MIL-STD-1474 requirements.

(3) Rationale. To identify safety-related deficiencies, an assessment and analysis of inherent and operational safety problems, as well as freedom from health hazard risks, must be conducted.

(4) Source. MIL-STDS 454, 882, 1472 and 1474; TB MED 523; AR 385-16; LOA, Para. 3(e) 2; and MIL-HDBK-759.

b. Issue 11. Is the HIP howitzer's human factors engineering (HFE) design acceptable?

		HAZARD PROBABILITY					
		FREQUENT	REASONABLY PROBABLE	OCCASIONAL	REMOTE	EXTREMELY IMPROBABLE	IMPOSSIBLE
SPECIFIC INDIVIDUAL ITEM		Likely to occur frequently	Will occur several times in life of item	Likely to occur sometime in the life of item	So unlikely, can be assumed that this hazard will not be experienced	Probability of occurrence cannot be distinguished from zero	Physically impossible to occur
FLEET OR INVENTORY		Continuously experienced	Will occur frequently	Will occur several times	Unlikely to occur, but possible	So unlikely, can be assumed that this hazard will not be experienced	Physically impossible to occur
HAZARD SEVERITY		A	B	C	D	E	F
CATASTROPHIC - May cause death or system loss	I	DEFICIENCY	DEFICIENCY	DEFICIENCY	DEFICIENCY	SUGGESTED IMPROVEMENT OR ACCEPTABLE	ACCEPTABLE
CRITICAL - May cause severe injury or illness, or major system damage	II	DEFICIENCY	DEFICIENCY	DEFICIENCY	SHORTCOMING	SUGGESTED IMPROVEMENT OR ACCEPTABLE	ACCEPTABLE
MARGINAL - May cause minor injury or illness, or minor system damage	III	DEFICIENCY	SHORTCOMING	SHORTCOMING	SUGGESTED IMPROVEMENT	SUGGESTED IMPROVEMENT OR ACCEPTABLE	ACCEPTABLE
NEGLIGIBLE - Will not result in injury or illness, or system damage	IV	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE

Figure B-1. Hazard Probability vs. Hazard Severity

(1) Scope. This issue assesses the HIP howitzer's capability for meeting the man-machine interface criteria outlined in MIL-STD-1472.

(2) Criteria.

(a) The HIP howitzer will meet the HFE requirements of MIL-STD-1472.

(b) The HIP howitzer will be capable of being operated, maintained and repaired at the unit level by 90% of MOS 13B soldiers.

(c) The HIP howitzer will be capable of being maintained and repaired at the intermediate level by 90% of the soldiers normally assigned to perform those duties.

(d) The HIP howitzer must provide working space for operation, maintenance and repair of the system by 90% of the soldiers normally assigned to perform those duties.

(e) The HIP howitzer must provide space for ingress and egress (normal and emergency) by a 95% of MOS 13B soldier dressed in arctic and/or NBC protective clothing.

(f) The HIP howitzer must provide seating that will accommodate 95% of MOS 13B soldiers and permit performance of crew tasks in all modes of operation without degradation.

(g) The HIP howitzer shall be designed so that controls and displays are visible, accessible and operable by 95% of MOS 13B soldiers when dressed in arctic and/or NBC protective clothing.

(h) The HIP howitzer must provide lighting for all tasks during all modes of operation IAW MIL-STD-1472. All controls, displays and indicators must be visible during all tactical operations.

(i) The HIP howitzer must provide ventilation and heating IAW MIL-STD-1472 for the full range of environmental conditions.

(j) The HIP howitzer must provide space for storage of water and onboard vehicle equipment (OVE) that permits an access by 95% of MOS 13B soldiers and does not require removal of other equipment.

(k) The HIP howitzer must provide manual backup capability for emplacement, lay, loading, and firing functions with performance equal to or better than the M109A2/A3 when in a similar configuration (e.g., power ramming or hand ramming).

(1) The HIP howitzer must provide speech intelligible intra-vehicle communications during all modes of operation including firing and/or while the vehicle engine is operating.

(3) Rationale. An assessment and analysis of the man-machine interface must be conducted to identify and correct human factors engineering deficiencies of the HIP howitzer.

(4) Source. AR 602-1; MIL-STD 1472; MIL-HDBK-759; Soldier Support Center.

c. Issue 12. Can the HIP howitzer unit operate in the range of natural environments expected for worldwide deployment?

(1) Scope. The capability of the HIP howitzer for operating in normal, desert, arctic, and tropic environments will be evaluated. The howitzer's human factors, safety, operational and crew performance characteristics will be stressed during operations in each environment. Operations stressing the system's technical characteristics and the man-machine interface will be conducted. All subsystems will be individually evaluated in addition to a total system being evaluated.

(2) Criteria.

(a) The HIP howitzer will be operable in hot, cold (with winterization kit), and basic climatic conditions IAW AR 70-38.

(b) Ninety percent of MOS 13B soldier's will operate, maintain, reload, and repair the HIP howitzer while wearing cold weather and MOPP IV equipment.

(3) Rationale. The HIP howitzer must be operable in all expected climates.

(4) Source. LOA, Para. 3e(3); AR 70-38; Soldier Support Center.

d. *Issue 15. Can the representative soldier and the HIP howitzer unit, after being trained IAW the test training support package (TTSP), adequately operate, maintain, and employ the HIP-howitzer?

(1) Scope. This issue assesses the ability of soldiers and units to effectively operate, maintain, and employ the howitzer in an operational environment. The adequacy and efficiency of the training and training support materials, envisioned for supporting the howitzer when fielded, will be evaluated. Training will be conducted on those individual and collective training tasks identified during the job/task analysis for operating and maintaining the HIP howitzer IAW approved doctrine and tactics. A pretest will be administered to all test players to ensure that they possess the skills and knowledge associated with their designated MOSs. Prior to test player training, the soldier must be capable of performing MOS tasks, as

specified in the appropriate soldier's manual. Upon completion of test players training, test players will be certified as being trained, IAW the TTSP, to perform individual and collective tasks to prescribed standards. The TTSP will contain the draft institutional POI, unit training materials (field manuals/circulars) to train the O&O Plan, and all institutional materials, training aids, and simulations envisioned for fielding with the HIP howitzer. All performance problems experienced during the test along with comments from test players will be analyzed to determine the effectiveness of the training program. Problems attributed to an inadequate training program will be used as a basis for revising the individual training plan, individual and collective training plan, institutional POI, unit OJT program, and modifications of the training devices. The draft test ARTEP will be evaluated based on the performance of the HIP howitzer section, platoon, battery, and battalion (investigative in nature).

(2) Criteria.

(a) The representative soldier must achieve the training standards specified in the TTSP for all HIP-related tasks.

(b) The training and test support materials must prepare the HIP howitzer section, platoon, battery, and battalion for performing HIP-related tasks IAW the TTSP Draft ARTEP standards.

(c) All training literature must be written at the 7th grade reading level and contain accurate illustrations and procedures for all training tasks.

(3) Rationale. The training program must answer the questions of what tasks must be performed in what manner, under what conditions, in response to what cues, and to what standard for the various MOSs in HIP units. The new equipment training (NET) team, using the TTSP, should prepare the test players and units to safely and efficiently operate and maintain the howitzer IAW approved doctrine and training. The planned institutional and OJT training programs must be capable of implementation within TRADOC schools and FORSCOM units.

(4) Source. USAFAS.

e. Issue 16. Do HIP training devices and simulators adequately train the soldier and unit to perform individual and collective tasks to the designated level of proficiency and is the training devices/simulators RAM adequate to ensure that they will be effective and logistically supportable when fielded?

(1) Scope. This issue assesses the adequacy of training devices and simulators developed for HIP howitzer training. An assessment of training transfer from the device to operational equipment will be conducted. The training time and the number of iterations required to achieve proficiency in the required tasks will be evaluated. RAM data on training devices will be collected. All maintenance actions required of the test players, instructors and contractors, for repairing training devices will be recorded. Parts

required to repair and return the HIP training devices to an operational condition will be reported, as will all operational and maintenance downtimes.

(2) Criteria.

(a) Training devices/simulators will train soldiers and units to perform designated individual and collective tasks to standards prescribed in the TTSP.

(b) The training device system must achieve a mean time between operational mission failures (MTBOMF) of at least 80 hours when operated in an institutional environment.

(3) Rationale. The capability of training devices for training individuals and HIP units to the TTSP standards requires testing and evaluation. Training devices must demonstrate the ability to correctly transfer skills from the training device to the actual equipment.

(4) Source. USAFAS.

7. Logistics.

a. *Issue 13. Is the HIP unit, when supported IAW the approved logistics concept, using the system support package (SSP), supportable through intermediate level maintenance?

(1) Scope. The HIP unit will be logistically supported IAW the logistics concept described in the doctrine and organizational support package. The system will adhere to the trilevel maintenance structure and forward support doctrine. Maintenance will be performed as described by the maintenance allocation charts (MAC) and IAW the instructions contained in the equipment publications (technical manuals) using the tools, TMDE, repair parts, and other support items contained in the SSP. Maintenance tasks contained in the MAC* will be verified by using representative soldiers to ensure that designated unit tasks, intermediate DS tasks, and intermediate GS tasks can be accomplished in an operational environment. If necessary, failures will be artificially introduced to ensure the adequate evaluation of maintainability and supportability issues. The SSP items, as identified in the DT/OT System Support Package Component Listings (SSPCLs), will be accounted for and available at the DT/OT test sites prior to test. Required SSP items include: operator's manuals; unit and intermediate maintenance technical manuals; unit and intermediate maintenance repair parts and special tools lists technical manuals; lubrication orders; repair parts; special tools; common tools; test, measurement and diagnostic equipment (including BIT and BITE); material handling and transporting equipment (e.g., M992 FAASV, M548 ARV); and other support equipment (e g., M578 LMV, generators, trucks, trailers).

*The MAC is a table of work-time figure representing the average times required to restore an item to a serviceable condition under typical field-operating conditions. This time includes preparation time, troubleshooting time, time required to perform specific maintenance tasks and time to verify that the system has been restored to serviceability.

(2) Criteria.

(a) The average time for operators and maintainers to accomplish assigned system maintenance tasks must be within the times required by the maintenance allocation charts (MAC) contained in the draft technical manuals.

(b) The mandatory portion of the unit combat PLL must support the howitzers during 15 days of combat operations.

(c) The howitzer must be recoverable by the designated recovery vehicle, for recovery situations up to and including fender depth mire. The HIP howitzer must be capable of being towed by like vehicles and/or by the FAASV (in emergency conditions) for distances of at least 15 kilometers, without damage to either vehicle and without requiring special tools or equipment.

(d) All required tools, TMDE, TMs, repair parts, maintenance personnel and their equipment, must be transportable in vehicles organic to the units at each maintenance level.

(e) Test measurement and diagnostic equipment (TMDE); including the howitzer's built-in-test (BIT), built-in-test equipment (BITE), and intermediate level maintenance test program sets; must correctly fault detect to at least 95 percent efficiency and isolate equipment faults to a line replaceable unit (LRU) to at least 90 percent efficiency of those faults they are capable of detecting.

(f) The maintenance tasks assigned to the unit and intermediate levels of maintenance, by means of the unit and intermediate TMs, will accurately reflect "unit" type and "intermediate" type maintenance tasks.

(g) The SSP (including all tools, calibration equipment, repair parts, TMs, and support items, as well as a listing of personnel and training requirements, and descriptions of the maintenance concept, expendable supplies and equipment, and fixed facilities) must permit accomplishment of all supply and maintenance tasks required to correct expected operational failures.

(h) The TMs must be prepared IAW MIL-M-63036A, MIL-M-63038B, MIL-HDBK-63038-1/2.

(3) Rationale. This issue subjectively examines logistics supportability as opposed to the quantitative assessment performed in the RAM

issue. The planned logistics support system must be compatible with current forward support doctrine and the Army logistics system. Achievement of criteria will demonstrate that HIP units can be fully supported when fielded.

(4) Source. DA PAM 700-50, Testing for Supportability; TRADOC letter, Subject: Logistics Supportability, Logistics Test and Evaluatiion, 26 Sep 83; TRADOC PAM 525-27-2, USA Operational Concept for Recovery and Evacuation.

b. Issue 14. Does the HIP unit's ammunition resupply system provide sufficient ammunition for the HIP howitzer?

(1) Scope. The tactical scenario will stress the unit's ammunition resupply capability for providing the required numbers and types of fuzes, projectiles, propelling charges, and primers. Ammunition resupply will be conducted during periods of reduced visibility, under varied terrain conditions, during day and night operations, and in various NBC mission-oriented protective postures, up to and including MOPP IV. The unit's ammunition resupply system includes the ammunition vehicles' hauling capacities, the numbers and skills of ammunition handling personnel, and the unit's standing operating procedures. This issue evaluates the system's capability for providing sufficient ammunition to meet the requirements of the OMS/MP for the twenty-four hour, wartime weighted average.

(2) Criteria. The unit's ammunition resupply system must provide the HIP howitzers with 301 complete rounds per tube per day.

(3) Rationale. An ammunition resupply rate of 301 complete rounds per tube per day is based on an analysis of the SCORES, Europe I, Sequence IIA scenario and is required for meeting the expected threat. The increased firepower capability of the HIP howitzer in combination with the requirements of the OMS/MP brings expanded demands for ammunition. The ammunition resupply system must be able to satisfy this demand without requiring major additions of equipment and personnel resources. The ammunition vehicles and personnel resources available in the HIP TOE are expected to satisfy these requirements.

(4) Source. LOA, Annex A, Para. 4f(4)(b).

APPENDIX C

SAMPLE FROM AN O&O PLAN, "OPERATIONAL DEPLOYMENT" SECTION

OPERATIONAL PLAN.

a. General. The operational plan of the HIP is compatible with Field Artillery doctrine as described in FM's 6-1, 6-20, 6-20-1, 6-20-2 and 6-50 but is expected to cause some modifications in roles, tactics and techniques described in those manuals because of the improved capabilities of the HIP as compared to previous models of the M109 howitzer. The HIP operational plan is compatible with operational concepts addressed in the Army 86 and Airland Battle 2000 concepts.

b. Employment.

(1) Divisional and separate brigade HIP battalions and armored cavalry regimental HIP batteries are organized, manned, and equipped to perform the direct support (DS) standard tactical mission. The battalion is also capable of performing the other standard tactical missions of reinforcing (R), general support-reinforcing (GSR), and general support (GS) plus nonstandard tactical missions. Task organization of M109AE2/E3 support elements allows for accomplishment of tactical missions by a HIP battery when accompanied by its slice of the support structure. A HIP battery may perform a mission independent of its parent unit (e.g., DS, while its parent battalion remains in a reinforcing role). Additionally, centralized tactical control makes possible cross attachment of firing platoons during localized surge periods.

(2) As part of the field artillery system, M109AE2/E3 battalions will also be found within Corps Artillery where they will augment the fires of divisional units during surge periods or in the attack of high density targets.

c. Operational Deployment.

(1) The HIP is operationally deployed to provide direct support fires to committed units within the division sector. A divisional field artillery battalion is habitually placed in direct support of a maneuver brigade. HIP units are normally deployed in firing platoon position areas with support centralized in a battery support area. Platoon position areas will be 1000-4000 meters apart. Platoons are further deployed so that an individual M109AE2/E3 operates within an assigned area as large as 1000 meters in diameter. The platoon headquarters will direct dispersion adequate to insure that no two howitzers are deployed within a single counterfire footprint. An alternate positioning technique to reduce vulnerability in an environment of intense local hostilities is the placement of two howitzer sections in close proximity to provide mutual support. Close positioning of all four fire units in each platoon is also possible if the ground threat is more serious than vulnerability to enemy counterfire. HIP batteries and subordinate fire units will be located in depth between 3 and 15 kilometers behind the forward line of troops (FLOT). Specific distances will vary with the tactical situation, the mission of the supported maneuver force, and the terrain.

(2) Displacement options available to and employed by HIP units are as discussed in FM's 6-20-1 and 6-50. The option selected reflects considerations of the overall tactical situation, immediate and future requirements of the supported unit, the characteristics of the terrain to be traversed/occupied, the distances involved, and the anticipated threat enroute.

(a) The M109AE2/E3 battalion and subordinate elements will normally displace by echelon, with the lowest level of control being the platoon. Time and tactical situation permitting, advance parties for position and survey point selection are dispatched prior to initiation of movement. These parties will normally be small with minimum security. The Positioning and Azimuth Determining System (PADS) will be used to establish battery/platoon survey points and update points along routes of march. Individual howitzers will have the capability to use on-board equipment to navigate to selected positions. Convoy elements will be small, thereby reducing any identifiable signature and the interruption of support to maneuver forces.

(b) Emergency/survivability displacements by an individual howitzer within its assigned position area will be conducted on order and/or in accordance with unit policy as dictated by the tactical situation or the intensity of the threat. Reconnaissance of alternate positions is not mandatory due to HIP's position determination capability and the ability of the howitzer to fire from any position offering operational safety.

(c) Because of this increased flexibility for movements by individual howitzers, the unit ammunition resupply vehicles (ARV) have a requirement to be equipped with an on-board communication capability as well as a vehicle navigation aid system. These capabilities will facilitate the resupply of ammunition from ARV to howitzer.

(3) HIP units are organized and equipped to perform limited self-defense. While the greater dispersion of the howitzer battery will normally preclude the establishment of effective defensive perimeters, all firing operations can take place without crew members leaving the improved armor protection of the howitzer, greatly enhancing survivability. Operating in this semi-autonomous mode, outside the protection offered by the current battery perimeter, also dictates that the ammunition and command and control vehicles supporting the HIP must be equipped with the same level of armor, mobility and self-contained operational capability as the HIP. A night vision device for the howitzer driver assists in providing self defense by enhancing the vehicle's capability to move during periods of limited visibility. Confrontation with anything larger than small dismounted enemy units, however, will require calling by radio for assitance or quickly moving to break contact. On-board communications will make early warning possible and allow HIP fire units to move when substantial combat forces pose a threat.

d. Communications Support Requirements.

(1) General. SINCGARS, a developmental communications system, is expected to support the bulk of the HIP communications requirement. SINCGARS is the new family of securable, jam resistant, VHF-FM tactical radios that will replace the current AN/VRC-12 series radios beginning in 1985.

(2) External communications. The HIP battalion and subordinate batteries will have the capability to communicate with higher headquarters through VHF/FM radio, both voice and digital-secure. Voice nets do not significantly differ from those addressed in FM 6-1. Digital communication nets will be similar to those outlined in Appendix E, FM 6-20. The SINCGARS, with appropriate communications security equipment, will be the primary communications means for these nets.

(3) Internal communications. The HIP battalion communicates internally via SINCGARS to the battery, platoon and fire unit level. Wire communication is used within headquarters, TOC and support areas and to provide backup communications with the fire units. Nets parallel those addressed in FM 6-1.

APPENDIX D

SAMPLE FROM AN O&O PLAN "OPERATIONAL MODE SUMMARY/MISSION PROFILE" SECTION

155mm Howitzer Improvement Program

Operational Mode Summary/Mission Profile

1. Purpose. This report provides the operational mode summary/mission profile for the armament subsystem of the M109E5 HIP equipped with a modified (i.e., M203 compatible) M185 cannon. Data provided includes:

a. Mission Profile (MP);

b. Operational Mode Summary (OMS);

c. Charge profile.

2. Definitions.

a. Mission Profile (MP)--A measure of the level of effort (in rounds, miles, No. of communications, etc.) a system can be expected to exert under various levels of combat intensity. MP consists of banded estimates for different levels of combat intensity. For this study, three levels are used:

(1) Sustained--The level of combat a system will experience 40 - 55% of the time it is committed. This is the least demanding level.

(2) Intense--The level that occurs 30 - 45% of the time;

(3) Surge--The level that occurs 5 - 15% of the time. This is the most demanding level.

b. Operational Mode Summary (OMS)--A single measure of level of effort developed as a weighted arithmatic mean across all three levels of combat intensity.

c. Charge Profile--A relative frequency distribution showing the propellant charges fired by the force.

3. Assumptions.

a. The variability in combat intensity across the front and between repetitions will approximate the variability across time.

b. Only conventional munitions are available.

c. Survivability moves are made every three missions.

d. Average distance traveled on a survivability move is 750 meters.

e. No high angle fire.

4. Parameters.

a. Weapon System: M109E5 (HIP) with modified M185 cannon.

b. Scenario: SCORES, EUROPE V.

c. Data Source: Target Acquisition/Fire Support Model (TAFSM) US Army Field Artillery School.

d. Prepared By:
Major John C. Traynham
Concepts and Studies Division, DCD
US Army Field Artillery School
Ft. Sill, Oklahoma 73503-5600
Phone: (Av) 639-4491/4974

5. Methodology.

a. Mission Profile.

(1) The Target Acquisition/Fire Support Model (TAFSM) was used to generate ammunition expenditures and the distribution of rounds fired by gun-target range.

(2) The total number of rounds fired by each 155mm howitzer was then extracted and, where necessary, scaled to 24-hours. This data was then subjected to a Tietjen-Moore test ($\alpha = 0.1$) to identify possible outliers.

(3) Firing levels for sustaining and surge periods were determined by using the time percentages as weapon percentiles when weapon were ordered by total rounds fired. The expenditures of the boundar weapons were taken as the bounding values for the specified level of combat. Intense levels were taken as the values between maximum sustaining and minimum surge expenditures.

Example: Sustaining--40 to 55% of the time
40th percentile weapon = Wpn No. 37
55th percentile weapon = Wpn No. 51
The rounds expended by the 38th and 51st weapons (when ordere by rounds fired) become the bounded estimate for Sustaining.

(4) Due to the nature of the data, final values were subjected to substantial rounding.

b. Operational Mode Summary. The OMS is a weighted mean of the Mission Profile. (Note: Due to the variability of the data, the OMS may not be a valid point estimate of overall combat intensity.) In computing OMS, duration mid-points of sustained and intense levels were used. The computational formula is:

$$OMS = P_s*R_s + P_i*R_i + 0.15*R_{su};$$

where:

P_s = Mean proportion of time in sustaining (mid-point);
R_s = Mean No. of rounds/Km/moves in sustaining;
P_i = Mean proportion of time in intense (mid-point);
R_i = Mean No. of rounds/Km/moves fired in intense;
R_{su} = Mean No. of rounds/Km/moves fired in surge.

c. Charge distribution. Total rounds fired for each gun-target range were extracted. The ranges were then used to determine the charge required to achieve that range (low-angle fire only). The total number of each type of charge that was consumed was calculated as well as its percentage of the total. Two cases were used in determining the charges required:

(1) Case 1: The minimum possible zone was selected. Criteria for going to a higher zone was when a target was within 1000 meters of a given zone's maximum range.

(2) Case 2: The maximum possible zone was selected subject only to a minimum elevation of 150 mils. The criteria for going to a higher zone was as above.

6. Analysis.

a. Unit firing rates varied from a minimum of 78 rounds to a maximum of 628. The mean expenditure was 388.1 rounds/weapon/day with a standard deviation of 137.0. There were no outliers.

b. The bulk (68%) of the weapons expended between 400 and 550 rounds; the modal class was 400 - 425 rounds and contained 27% of the weapons. Weapons falling outside of this range were approximately uniformly distributed. (Chart 1)

c. Differences between the previous OMS/MP and the one contained herein appear reasonable and within the limits to be expected based on the change in scenarios and differences in weapons and force structure.

d. Since moves are primarily a function of rounds and missions (survival moves dominate tactical moves in this scenario, in both numbers and distance traveled), mobility data follows a similar distribution.

7. 155mm Operational Mode Summary/Mission Profile

a. Mission Profile.

Level	Firepower[1]	Mobility[2]
Sustained (40 - 55%)	40 - 80 Missions 200 - 400 Rounds	13 - 25 Moves 10 - 25 Km.
Intense (30 - 45%)	75 - 115 Missions 400 - 550 Rounds	25 - 40 Moves 20 - 40 Km.
Surge (5 - 15%)	110 - 140 Missions 550 - 650 Rounds	35 - 50 Moves 25 - 50 Km

[1] Per tube per day
[2] Includes survivability move every 2 - 4 missions.

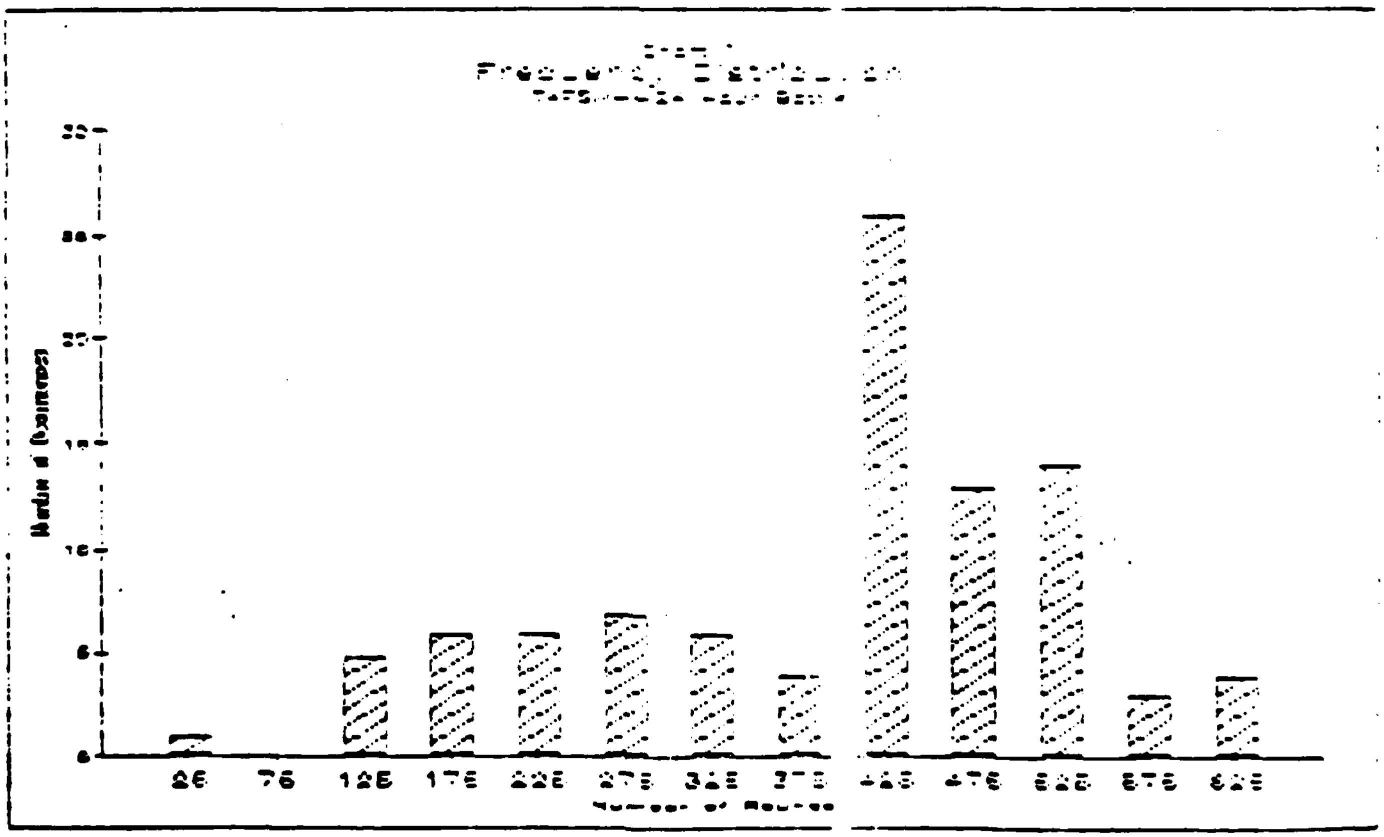
b. Operational Mode Summary.

(1) Firepower: 83 Missions/Tube/Day
411 Rounds/Tube/Day

(2) Mobility: 28 Moves/Weapon/Day
25 Km/Weapon/Day

c. Charge Distribution.

Case	GB	WB	M119	M203
Maximum Zone	13%	65%	12%	10%
Minimum Zone	28%	50%	12%	10%



APPENDIX E

OUTLINE OF THE REQUIRED OPERATIONAL CAPABILITY (ROC) DOCUMENT (FROM AR 71-9)

Format for Letter of Agreement, Required Operational Capability, Joint Service Operational Requirements, Letter Requirement, and Training Device Requirement. LOA, ROC, JSOR, LR, and TDR will be in the format below. Limit information to that necessary for an HQDA decision. The basic document should not exceed four pages. In the LOA, use less detail and bands of broader performance than in the ROC, LR, and TDR. The JSOR will initially have broader bands of performance. As the development process continues, these bands of performance should become more narrow. Terms in each paragraph of the LOA will evolve into more specific terms in the ROC, LR, and TDR. Attach the mission profiles to the LOA as an annex.

1. Title.

a. Give a descriptive title for the program.

b. Add CARDS Reference Number (ODCSOPS will assign this number).

2. Need/threat.

State what is needed. Briefly describe the threat and operational/training deficiency need for the system. Include the enemy's capability to detect, identify, locate, avoid, suppress, destroy, or otherwise counter the system. Describe the responsive threat over time to support evolutionary development when applicable.

3. Time frame and IOC.

List the time frame for the LOA and IOC for the ROC, LR, JSOR, and TDR. Include dates of successive models when known.

4. Operational/organizational plan.

In a brief paragraph state the following:

a. How the equipment will be used.

b. Deployment requirements.

c. Geographical areas of use.

d. Weather and climatological factors to be considered during equipment operations.

e. Battlefield conditions (such as ECM, smoke, and dust) in which the system will operate.

f. The type of units that will use and support the equipment. Attach the Operational Mode Summary/Mission Profile to the LOA as an annex.

5. Essential characteristics.

Describe only the main operational features of the system. Included are counter-countermeasure capabilities, health and physical security, safety, environmental quality control, HFE requirements, transportability and reliability, availability, and maintainability. Performance must be responsive to battlefield environmental conditions of continuous combat (such as full ECM, smoke aerosols, electromagnetic environmental effects (E3), rain, fog, haze, and dust). Performance and reliability characteristics will be expressed in bands of performance. Those which are not suitable for banding will be stated as a single value. During development, commercial, other service, NATO or other allied nation characteristics of existing or programed systems should be considered for inclusion. This will be with a view toward establishing the basis for interoperability, coproduction, or standardization. Bands of performance should be flexible enough to consider competing systems of other services or allied nations. The stated bands of performance or single value characteristics will be adjusted only after the combat and the materiel developers agree that such changes are necessary. DCSOPS will approve changes for documents previously approved by DCSOPS. Changes to all other documents will be made jointly by TRADOC and DARCOM. The requirements and provisions for the following must be considered:

a. Interoperability.

b. Continuity of Operations (CONOPS).

c. Security.

d. Transportability.

e. Reliability, availability, and maintainability.

f. Standardization, including commonality for hardware and software to which the system will adhere.

g. Nuclear survivability, non-nuclear survivability; NBC contamination and decontamination survivability.

h. Individual and collective protection equipment.

i. Adverse weather and reduced visibility conditions (smoke and obscurants), operations, and military operations on urbanized terrain, where applicable.

j. Communications.

k. Airdrop certification and jumppack.

l. Preplanned product improvements (para 3-37).

6. Technical assessment.

In the LOA, divide this paragraph into operational, technical, logistical, safety, health, HFE, energy consumption, training, personnel, and manpower subparagraphs. In each subparagraph describe what the combat and materiel developers, logistician, training developer, and personnel manager must undertake to produce the total system. Include a listing of major events and dates. In the ROC, include a brief paragraph about the technical effort required. Address major areas for full scale development in terms of scope, technical approach, and associated risks in high, medium, low, or similar categories. For NDI, briefly outline planned market survey effort and/or military suitability evaluations.

7. Logistic support plan.

Briefly describe the logistic support plan. Include statement that the logistic support plan will be available for evaluation during OT I (if LOA) or for testing during OT II (if ROC, JSOR, LR, or TDR).

8. Training assessment.

Discuss the need for system TDs. When required, include

device description as an annex to the ROC or LR. NET operator and maintenance personnel training, technical manuals (TM), and training materiel requirements will be stated in terms of needs for both institutional and unit training. Include a statement that the training support plan will be available for evaluation during OT I (if LOA) or for testing during OT II (if ROC, LR, JSOR, or TDR).

9. Manpower/force structure assessment.
Estimate manpower requirements per system, using unit, and total Army by component (Active, ARNG, USAR). Identify manpower savings resulting from replaced systems, if any. Include a statement which will require an assessment of alternatives to reduce manpower requirements and an assessment of force structure implications resulting from system inclusion in the total force by component. If the force structure assessment exceeds current programed force structure levels, then identification of force structure trade-offs within mission area or mission elements are required. Trade-off analysis should be addressed to the degree necessary to bring the force structure assessment within current programing levels, if possible.

10. Standardization and interoperability.
Discuss other Service, NATO, and other foreign interest in the program. Identify similar programs contemplated by other Services, NATO, or other allies.

11. Life cycle cost assessment.
Add life cycle cost assessment as appendix 1 to the requirements documents. Provide total life cycle costs using mainly summary parametric estimating techniques. State the major life cycle phases of R&D investment nonrecurring, investment recurring, and operation and support. Also, include the design to cost goals. As much as possible, show the estimated cost of major items or components below the system level. (These data should be consistent with the MSRS and BCE.

12. Milestone schedule.
Provide a listing of significant events with dates to occur between approval of document (LOA, LR, ROC, TDR, and so forth) and the next scheduled IPR. The following should be included ROC, LR, TDR, LOA approval, program management documentation (PMD), DT, OT, other test (Market/User Survey for NDI), and IPR.

Annex A—Coordination.
List all major commands, other Services, allied nations and activities with whom the LOA, ROC, LR, TDR and JSOR was coordinated. Provide full rationale for nonacceptance of comments, if any.

Annex B—Operational Mode Summary/Mission Profile Annex.
List tasks and conditions for frequency and urgency viewed for system employment in military operations. The mission profile is logically derived from the operational and training concept. It provides the starting point for developing the system characteristics.

Annex C—COEA Annex.
Executive summary of the COEA. Classify as required. Withdraw after HQ, TRADOC approval of the requirements documents and handle as a separate document for transmittal as needed.

Annex D—Rationale Annex.
Support various characteristics stated in the LOA, ROC, JSOR, LR, and TDR. This provides an audit trail and rationale for determining how the characteristics were derived.

Annex E—RAM Rationale Annex.
Executive summary of the RAM Rationale Report contains guidance on the preparation of both the RAM Rationale Report Annex and RAM Rationale Report.

Annex F—Training Device Annex.
(When required). Include description of needed TDs. A separate annex is required for each TD. The following format will be used:

1. Title.
2. Operational/Organizational Plan.
3. Essential characteristics.
4. Technical assessment.
5. Logistical assessment.
6. Training assessment.
7. Manpower assessment.
8. Funding.

Notes:

1. Withdraw all annexes except annexes A and B before forwarding an LOA to HQDA.
2. Withdraw all annexes except annex A before forwarding an LR, ROC, JSOR, or TDR to HQDA.
3. Include only annex A when distributing the approved document.
4. Send the BOIP/QQPRI with the ROC and TDR when they are sent to HQDA for approval. When the BOIP/QQPRI are not submitted with the requirements documents, the transmittal letter will contain a statement about the projected submission date.

APPENDIX F

SAMPLE FROM A QUALITATIVE AND QUANTITATIVE REQUIREMENTS INFORMATION (QQPRI) DOCUMENT

Qualitative and Quantitative Personnel Requirements
Information (QQPRI) for POWER PLANT ELEC: 15KW 400HZ SSDED,
LIN: Z50245, NETP No. TS 84-26

1. REQUIREMENT INFORMATION:

a. Requirement or Procurement Directive: ROC f/SSDED Gen Sts 15-60kW appd 850703.

b. Type Classification (TC) Date: 880930.

c. First Unit Equipped Date (FUED): 900930.

d. Army Modernization Information Memorandum (AMIM) Number: A763.

e. QQPRI Preparer: SSG Harold F. Kinch, 2 Feb 87, U.S. Army Troop Support Command, ATTN: AMSTR-MSE, 4300 Goodfellow Boulevard, St. Louis, MO 63120-1798, AUTOVON 693-0646.

2. DESCRIPTION AND DIRECT PRODUCTIVE ANNUAL MAINTEANNCE MAN-HOURS (DPAMMHs):

a. Principal Item: LIN: Z50245 - POWER PLANT ELEC: 15KW 400HA SSDED. The SSDED POWER PLANT will consist of two (2)Gen Sets 15 KW 400 HZ SSDED, LIN Z29543 mounted on two (2) military M200A1, 2½ ton trailer with connecting cables, mounting hardware and ancillary equipment.

b. Component Major Item:

(1) LIN: Z29537 - GEN SET 15KW 400HZ (SSDED).

MOS	UL	IDS	IGS
44B			
52D	132	100	50

NOTE: DPAMMHs for this item were estimated by Major Subordinate Command based on similar items of equipment.

(2) LIN: E02807 - CHASSIS TRAILER: GEN 2½ TON M200A1.

MOS	UL	IDS	IGS
63B	32		
63W		20	

NOTE: DPAMMHs for this item were taken from the Manpower Requirements Criteria.

c. Total DPAMMHs by MOS, SSI, or OPMCS for subparagraphs a and b above:

(1) Developmental Items:

MOS	UL	IDS	IGS
44B			
52D	132	100	50

(2) Type Classified Items:

MOS	UL	IDS	IGS
63B	32		
63W		20	

d. Associated Support Items of Equipment (ASIOE): NA.

3. NUMBER DIRECT OPERATORS REQUIRED TO CREW OR OPERATE EQUIPMENT: No additional personnel will be required to operate or man the SSDED; existing sources will be used.

4. DUTY POSITIONS BY DESCRIPTIVE TITLE:

Position	Title	Suggested Placement
Operator:	General Purpose User (GPU)	Any MOS
UL:	Power-Generation Equipment Repairer	MOS 52D
	Light-Wheel Vehicle Mechanic	MOS 63B
IDS:	Metal Worker	MOS 44B
	Power-Generation Equipment Repairer	MOS 52D
	Wheel Vehicle Repairer	MOS 63W
IGS:	Metal Worker	MOS 44B
	Power-Generation Equipment Repairer	MOS 52D

5. INDIVIDUAL UNIQUE DUTIES, TASKS, AND CHARACTERISTICS:

a. MOS 44B performs duties and tasks as listed in AR 611-201.

b. MOS 52D performs duties and tasks as listed in AR 611-201.

c. MOS 63B performs duties and tasks as listed in AR 611-201.

d. MOS 63W performs duties and tasks as listed in AR 611-201.

6. NETP NUMBER AND NET TRAINING BASE REQUIREMENTS:

a. NETP Number: TS 84-26.

b. Training will be accomplished with the SSDED Skid Mounted Generator Sets.

APPENDIX G

TRAINING IMPACT WORKSHEET

TRAINING IMPACT WORKSHEET

(TRADOC Suppl 1 to AR 71-2)

SCHOOL: UPDATED TASK LISTS | QQPRI TITLE

BOIP TITLE: IN COLUMN D | BOIP NO. | LIN

LINE	MOS a	CMF b	ASI c	DUTY FUNCTION d	AR 611-201 ACTION e	TYPE/LENGTH OF TRAINING RES f	ETM g	SOJT h	CHANGE IN TRAINING TIME i	DRAFT MATERIAL AVAILABLE j	REMARKS k

POC	AUTOVON	SIGNATURE OF TRAINING DEVELOPER

APPENDIX H

SAMPLE FROM A BASIS OF ISSUE PLAN (BOIP)

BASIS OF ISSUE PLAN COVER SHEET

DATE OF RUN 86/02/28

1. PAGE 1

2. BOIP SERIAL NUMBER	3. CHG NO.	4. INITIAL OR REVISION DATE	5. ESTIMATED DATE OF TC STD-A	6. 1ST UNIT EQP. DATE	7. ESTIMATED UNIT COST	8. QQPRI STATUS	9. STANDARD STUDY NO.	10. CARDS NO
95-0634-X		85/02/28	~~87/10/15~~ 86/03/30	~~87/10/15~~ 86/3/30	650	F/B	6245030041U	~~444~~ 0211F

11. NETP	12. LINE ITEM NUMBER	13. NOMENCLATURE	APC = XB (TASKED TO SCHOOL(WORKING))	14. ASN	15. RIC	16. SC	17. AB DA TC	SSC
N/A	Z09518	BAYONET MULTIPURPOSE: W/SCABBARD		2	01S	24	007 F2	NOB

ITEM 18 → 18. ORGANIZATIONAL/OPERATIONAL CONCEPTS AND MOS/QQPRI INFORMATION (BOING-BASIS OF ISSUE NARRATIVE GUIDANCE)

THE MULTIPURPOSE BAYONET MOUNTS ON THE STANDARD ARMY RIFLE (M-16 SERIES) AND THE XM-4 CARBINE. THE BAYONET WILL BE USED AS A SECONDARY WEAPON FOR HAND-TO-HAND COMBAT WHEN MOUNTED ON THE M-16/~~M-4~~ WEAPON, OR AS A COMBAT KNIFE AND WIRE CUTTER WHEN DISMOUNTED.

MOSs → QQPRI INFORMATION: OPERATOR: DESIGNATED BY THE COMMANDER.
UNIT MAINT: 76Y
DS/GS: 639

THIS ITEM IS APPROPRIATE FOR PUBLICATION IN AR310-34.

BASIS OF ISSUE INFORMATION: THE MULTIPURPOSE BAYONET, LIN Z09518, WILL REPLACE ON A 1 FOR 1 BASIS THE BAYONET, M-7, LIN B49272, IN THE CLOSE COMBAT FORCES OF ALL INFANTRY BATTALIONS (TO INCLUDE RGR), SPECIAL FORCES OPERATIONAL BATTALIONS, AND COMBAT ENGINEER BATTALIONS (DIVISIONAL AND CORPS) AND COMPANYS (SEP. BDE) THAT HABITUALLY OPERATE WITH THE INFANTRY IN A CLOSE COMBAT ROLE.

19. ASSOCIATED /RELATED BOIP/LIN

LINE ITEM A.	NOMENCLATURE B.	ASSOC BOIP NO. OR STD-LCC C.	REMARKS D.

20. REPLACED EQUIPMENT

LINE ITEM A.	NOMENCLATURE B.	PRINCIPAL/ASSOC C.	REMARKS D.
B49272	BAYONET-KNIFE: W/SCABBARD FOR M16A1 RIFLE	IN PRINCIPAL	0101

APPENDIX I

SAMPLE FROM A "SUPPORT ITEM UTILIZATION SUMMARY"

LSA-05 LOGISTIC SUPPORT ANALYSIS RECORD DATE 12/06/86 PAGE 001

SUPPORT ITEM UTILIZATION SUMMARY

END ITEM ACRONYM	LSA CONTROL NUMBER	MFR PART NUMBER	ITEM NAME	SERVICE DESIGNATION	ITEM CATEGORY CODES SELECTED
M992	A	8750062	FLD ARTY AMMO SPT V	ARMY	B,M,X,Y,Z,9,

SUPPORT ITEM PART NUMBER 10903378 ITEM NAME LEVER,REMOTE CNTRL ITEM CATEGORY CODE V

MAINT LEVEL	LSA CONTROL NUMBER	ITEM NAME	TASK CODE	TASK IDENTIFICATION	TASK FREQ	ELAP TIME	MAN-HOURS	QTY PER TASK
ORG	AF	STEER CONT INSTL	JGOXXAA	REPAIR STEERING SHAFT	.06	.18	.18	0.1
			JGOXXAD	REPAIR REMOTE CONTROL LEVER	.01	.13	.13	1.0
**** ANNUAL REQUIREMENTS FOR MAINT LEVEL ******************						.01		.02
**** ANNUAL REQUIREMENTS FOR ALL MAINT LEVELS *************						.01		.02

SUPPORT ITEM PART NUMBER 10903381 ITEM NAME SHAFT,STRAIGHT ITEM CATEGORY CODE V

MAINT LEVEL	LSA CONTROL NUMBER	ITEM NAME	TASK CODE	TASK IDENTIFICATION	TASK FREQ	ELAP TIME	MAN-HOURS	QTY PER TASK
ORG	AF	STEER CONT INSTL	JGOXXAE	REPAIR STRAIGHT SHAFT	.01	.18	.18	1.0
			JGOXXAF	REPAIR REMOTE CONTROL LEVER	.01	.14	.14	0.1
	AFB	STEERING HOUSING	MGOXXAA	REMOVE/REPLACE STEERING HOUSING	.01	.22	.22	0.1
**** ANNUAL REQUIREMENTS FOR MAINT LEVEL ******************						.01		.01
**** ANNUAL REQUIREMENTS FOR ALL MAINT LEVELS *************						.01		.01

TASK TIMES

APPENDIX J

CLUSTER ALGORITHMS FROM WHEATON, FINGERMAN, AND BOYLAN (1975)

ALGORITHM 1---GENERALIZABILITY

INPUT ARRAYS

Let $\underline{X} = [x_{ij}]$ be the job objective-behavioral element matrix, arranged so that objectives in the same cluster are contiguous. $\underline{X}$ has I rows, corresponding to job objectives; in the present case I = 266. $\underline{X}$ has J columns corresponding to behavioral elements.

Let $\underline{C}$ $[c_k]$ be a K-by-1 vector containing the number of job objectives in each of the K clusters. In the present case K = 16. The entries in $\underline{C}$ are ordered consistently with the order of clusters in $\underline{X}$. The values of each c_k for the present case may be computed from data.

WORKING ARRAYS

Let D = $[d_j]$ be a J-by-1 vector containing the frequency with which each of the J behavioral elements occurs across the entire set (or domain) of job objectives.

Let $\underline{F} = [f_{kj}]$ be a K-by-J matrix containing the frequency with which each of the J behavioral elements occurs within each of the K clusters of job objectives.

Let $\underline{W} = [w_{kj}]$ be a K-by-J matrix which contains the generalizability weight for each element in each cluster.

OUTPUT ARRAYS

Let $\underline{G} = [g_i]$ be an I-by-1 vector containing generalizability index values for each of the I job objectives.

OPTIONS

Let $\underline{R} = [r_i]$ be an I-by-1 vector containing the rank of the generalizability index value for the i^{th} job objective, ranking being performed independently within each cluster.

Let $\underline{Z} = [z_i]$ be an I-by-1 vector containing the standardized generalizability index value for the i^{th} job objective, standardization being performed wtihin each cluster using the within-cluster mean and standard deviation for the g_i's in that cluster.

POINTERS AND INDEX VARIABLES

i ranges from 1 to I across the I job objectives (e.g. rows of $\underline{X}$).

j ranges from 1 to J across the J behavioral elements (e.g. columns of $\underline{X}$).

k ranges from 1 to K across the K clusters (e.g. rows of $\underline{F}$).

LL "lower limit" pointer, used to indicate the lowest job objective in a given cluster.

UL "upper limit" pointer, used to indicate the highest job objective in a given cluster.

COMPUTING ALGORITHM NO. 1

Step 1.) For j := 1 to J,

$$d_j := \sum_{i=1}^{I} x_{ij}.$$

Step 2.) Comment: $\underline{D}$ vector is now computed.

Step 3.) LL := 1.

Step 4.) UL := c_1.

Step 5.) Comment: LL and UL define the lower and upper limits of Cluster 1.

Step 6.) k := 1.

Step 7.) For j := 1 to J,

$$f_{kj} := \sum_{i=LL}^{UL} x_{ij},$$

$$w_{kj} := (f_{kj} ** 2) / d_j.$$

Step 8.) If k = K GO TO Step 14.

Step 9.) LL := LL + c_k.

Step 10.) k := k + 1.

Step 11.) UL := UL + c_k.

Step 12.) Comment: LL and UL define the lower and upper limits of Cluster k.

Step 13.) GO TO Step 7.

Step 14.) k := 1.

Step 15.) i := 1.

Step 16.) UL := c_k.

Step 17.) $g_i := \sum_{j=1}^{J} (x_{ij} * w_{kj})$.

Step 18.) $i := i + 1$.

Step 19.) If i GT I GO TO Step 24.

Step 20.) If i LE UL GO TO Step 17.

Step 21.) $k := k + 1$.

Step 22.) $UL := UL + c_k$.

Step 23.) GO TO Step 17.

Step 24.) Output $\underline{G} = [g_i]$.

Optional

Step 25.) $LL := 1$.

Step 26.) $k := 1$.

Step 27.) Execute Algorithm RANK ($\underline{G}(LL)$, c_k, $\underline{R}(LL)$).

Step 28.) Comment: Algorithm RANK ranks c_k values beginning in address $\underline{G}(LL)$, and places the ranks in array $\underline{R}$ beginning at address LL.

Step 29.) Execute Algorithm STANDARD ($\underline{G}(LL)$, c_k, $\underline{Z}(LL)$).

Step 30.) Algorithm STANDARD computes standard score values for the c_k scores beginning in address $\underline{G}(LL)$, and places them in array $\underline{Z}$ beginning at address LL.

Step 31.) $k := k + 1$.

Step 32.) If k GT K GO TO Step 35.

Step 33.) $LL := LL + c_{(k-1)} + 1$.

Step 34.) GO TO Step 27.

Step 35.) Output $\underline{R} = [r_i]$.

Step 36.) Output $\underline{Z} = [z_i]$.

Step 37.) STOP

ALGORITHM 2---ELEMENT COVERAGE

INPUT ARRAYS

Let $\underline{X} = [x_{ij}]$ be the job objective-behavioral element matrix. $\underline{X}$ has I rows, corresponding to job objectives; in the present case, I = 266. $\underline{X}$ has J columns corresponding to behavioral elements.

Let $\underline{S} = [s_n]$ be an N-by-1 vector listing the job objectives in the sample to be analysed. Each entry in $\underline{S}$ is a row number in the matrix $\underline{X}$ that corresponds to a job objective included in the sample.

WORKING ARRAYS

Let $\underline{D} = [d_j]$ be a J-by-1 vector containing the frequency with which each of the J behavioral elements occurs across the entire domain of job objectives.

Let $\underline{F} = [f_j]$ be a J-by-1 vector containing the frequency with which each of the J behavioral elements occurs within the sample of objectives to be evaluated.

Let $\underline{D}' = [d_j']$ be a J-by-1 vector which indicates which elements occur at least once across all job objectives in the domain, that is, if d_j is greater than or equal to 1, then d_j' equals 1; otherwise d_j' equals 0.

Let $\underline{F}' = [f_j']$ be a J-by-1 vector which indicates which elements occur at least once in the sample of job objectives being analysed. Thus, f_j' equals 1 when f_j is at least 1, and f_j' is 0 otherwise.

OUTPUT STATISTICS

Let PROP be the proportion of behavioral elements which occur in the domain ($\underline{X}$) and also in the sample.

Let CHISQ be a measure of goodness-of-fit between the frequency with which an element occurs in the domain and in the sample. CHISQ will be distributed as chi-square under a null hypothesis that the frequencies in the domain and sample are perfectly associated; it will have J=1 degrees of freedom (DF in the algorithm) in the present case (J-1), since all J elements occur at least once in the domain. CHISQ may be tested for significance ("poorness of fit").

Let PHIMAX be a measure of correlation between the frequency with which an element occurs in the domain and in the sample . It is derived directly from CHISQ.

POINTERS

i ranges from 1 to I across the I job objectives (e.g. rows of $\underline{X}$).

j ranges from 1 to J across the J behavioral elements (e.g. columns of $\underline{X}$).

n ranges from 1 to N across the N job objectives in the sample (e.g. rows of $\underline{S}$).

COMPUTING ALGORITHM NO. 2

Step 1.) For j := 1 to J,

$$d_j := \sum_{i=1}^{I} x_{ij}.$$

Step 2.) Comment: $\underline{D}$ vector is now computed.

Step 3.) For j := 1 to J,

$$f_j := \sum_{n=1}^{N} x_{s_n j}.$$

Step 4.) Comment: $\underline{F}$ vector is now computed.

Step 5.) For j := 1 to J, execute Steps 6 and 7.

Step 6.) If d_j GE 1 $d_j' := 1$ ELSE $d_j' := 0$.

Step 7.) If f_j GE 1 $f_j' := 1$ ELSE $f_j' := 0$.

Step 8.) $\text{PROP} := [\sum_{j=1}^{J} (d_j' * f_j')] / \sum_{j=1}^{J} d_j'$.

Step 9.) For j := 1 to J,

$$d_j := d_j * (N/J).$$

Step 10.) $\text{CHISQ} := \sum_{j=1}^{J} [(f_j - d_j)^2 / d_j]$, for $d_j \neq 0$.

Step 11.) $\text{DF} := \sum_{j=1}^{J} d_j' - 1$.

Step 12.) $\text{PHIMAX} := \text{SQRT} [\ \text{CHISQ} / (\sum_{j=1}^{J} f_j) / (\text{DF})\ ]$.

Step 13.) OUTPUT PROP, CHISQ, DF, PHIMAX.

Step 14.) STOP

MANPRINT METHODS MONOGRAPH:
AIDING THE DEVELOPMENT OF MANPOWER-BASED SYSTEM EVALUATION

CONCEPT PAPER FOR PRODUCT FIVE - OPERATIONS AND MAINTENANCE JOBS PREDICTION AID

Lanny K. Walker, Cecil D. Johnson, and David L. Payne, Hay Systems, Inc.
Carl F. Asiala, Perceptronics, Inc.

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Concept Paper for Product Five--
Operations and Maintenance Job Prediction Aid

OVERVIEW

INTRODUCTION

A general problem that must be solved to aid the Army in developing and acquiring systems that can be manned adequately is that of determining how to evaluate hardware and software plus training designs (prior to the development of a prototype) so that manning requirements and alternative training strategies, interface and function allocation, and tactical solutions can be determined and provided to Army decision makers.

The concept for a product which will aid MANPRINT personnel in predicting the operations and maintenance jobs required with respect to a given system and the number of operations and maintenance personnel per job per system is described. The purpose of this product is to determine the number of personnel (per job) required to operate and maintain system hardware so that the Army has a basis to evaluate personnel availability.

Product Five is defined as a software suite including a set of decision aids and models embedded in a common software environment (a model bank); a data bank; working files; and user interface software.

Data input sources are identified. State-of-the-art computerized models with user friendly interface are proposed. An approach to job component aggregation that can be compared to a linear programming model is set forth.

The major decision processes supported by the product are: (1) task and task data generation; (2) task and duty model aggregation into larger jobs or job components; (3) workload determination; and (4) generation of a report on manpower and personnel requirements. Personnel using this product will require access to initial hardware and software interface designs, mission-function task analyses, battlefield conditions and performance criteria.

This paper presents a conceptualized design of an operation and maintenance jobs prediction aid. Application of this MANPRINT aid will provide an imposed process for evaluating new system acquisitions impact on Army manning.

PROBLEMS

The Army must ensure that its soldiers will be able to operate and maintain system hardware and software to a level of performance sufficient to achieve mission success. During the past several years, ARI has convincingly demonstrated to the Army that this goal is possible only when manpower, personnel, and training issues (MPT) are considered early in the acquisition process - during the system design stages.

Presently, little attention is paid to MPT issues during system acquisition. Consequently, systems are frequently fielded which cannot be satisfactorily manned or for which performance does not measure up to specifications. MANPRINT is a set of guidelines, regulations, procedures, methods and processes that attempts to maximize the probability that systems

are developed and acquired which can be effectively operated and maintained by available numbers of future soldiers having varied, but identifiable, skills and capabilities.

There are two general problems that must be solved to aid the Army in insuring that it is developing and acquiring systems that can be manned adequately:

(a) Determining how to develop and communicate information to materiel developers that will influence hardware and software design so that resulting systems can be manned and can achieve mission success with available soldiers.

(b) Determining how to evaluate hardware and software plus training designs (prior to the development of a prototype) so that manning potentials and alternative training, interface and function allocation, and tactical solutions (in the presence of manning deficits) can be determined and provided to Army decision makers.

This concept paper for Product Five addresses problem area (b) discussed above. Any solution to this problem must be sufficiently complete so as to provide a useful aid to the Army. Therefore, the solution of three specific, procedural problems is required. These are:

(1) How are the various required classes of information provided by the product developed at the detailed, working level?

(2) Where will the required data (for the development of this information) be obtained?

(3) How can the use and acceptance of the product that attempts to answer these problems be insured? That is, who should be using the product and in what manner should communication take place?

OBJECTIVES

Developing information that affects designs and evaluating designs require that Army personnel make difficult decisions. By the end of this program, ARI will have finished products that aid personnel in making those decisions. The personnel being aided will have experience in the domains to which the decision aids apply, but it cannot be assured that they will have any computer experience. Product Five cannot require the creation of new organizations, nor can its use absorb large numbers of additional person hours. The objective is to improve the acquisition process by aiding the personnel that work currently in that process. The specific decision-aiding product that ARI wants at the conclusion of this program is a product to aid in evaluating system designs.

Product Objectives. Product Five is a product to aid in evaluating system designs. It is to be used following the initial detailed interface design, but prior to the decision to fund the hardware and software prototype. Product Five will aid MANPRINT personnel in predicting the operations and maintenance jobs required and the number of operations and maintenance personnel per job per system. The purpose of this product is to determine the

number of personnel (per job) required to operate and maintain system hardware so that the Army has a basis to evaluate personnel availability. User's of Product Five will have access to initial hardware and software interface designs, mission-function-task analyses, battlefield conditions, and performance criteria. It should be stressed that the requirement to be identified is at the job, not the MOS, level. The goal of this specific product is to determine numbers of required personnel per system that can be associated with clusters of functions and tasks (both operations and maintenance).

If computer hardware is required for the product to be developed or used, it must be hardware that is in residence at appropriate Army locations, or scheduled to be acquired by those locations, or accessible via secure networks and lines to those locations.

Concept Paper Objectives. This program is being conducted in three stages. As each stage is completed, that stage's deliverables (concept papers, design specifications, finished products) will become the property of the U.S. Army. This report provides the results of the concept paper stage of the program.

The objectives of this concept paper for Product Five are to discuss and describe, at a high level of detail, the following significant issues:

(1) How Product Five will be developed.

(2) What data will be required for Product Five.

(3) Where all required data are now found or will be found.

(4) What classes of information and/or aiding Product Five will provide.

(5) How all information and/or aiding to be provided will be produced by Product Five.

(6) How Product Five will insure the acceptability and usability of its output. This will include identification of the most fruitful users of each product by organization, job type, and acquisition cycle phase, and the methods of communication required to insure user acceptability.

(7) How Product Five will train its users.

(8) The number of person-hours required to use Product Five for major acquisitions.

(9) The means for achieving institutionalization of Product Five within the Army organizational context, as it now exists.

After a brief discussion of the scope and a summary of the technical concept, each of these critical issues are discussed in the major sections of this concept paper report.

SCOPE

This concept paper describes Product Five of this MANPRINT effort, which will aid in the estimation of quantitative manpower and personnel requirements for systems under development. We will first provide a description of the family of decision aids and models and associated data bases which make up this product, along with the architecture for integrating them into a user-friendly configuration. We will then describe the means for developing the product, and both selected and non-selected candidate methodologies considered for inclusion in the product will be discussed. Such design and benefit considerations as the availability of the required input data, the developmental and user variables, design and developmental risks, and the expected benefits to the Army will be presented and critically examined. Also, the manner of installing the product, training users, and assuring the acceptability of the product to both analysts and managers will be discussed. In short, the paper presents a product description and additional information which together will provide a basis for evaluating the probable technical validity and usefulness of Product Five as a justification for its further development and implementation.

TECHNICAL CONCEPT

The conceptualized design for Product Five can be described in terms of its major modules as depicted in Figure 1. The major decision processes accomplished by the product are: (1) task and task data generation, (2) task and duty module aggregation into larger jobs or job components, (3) workload determination, and (4) generation of an output report on manpower and personnel requirements. Certain modules and data inputs are identified as optional for the analyst. For example, if tasks are already identified with adequate task descriptions available from another source, the analyst may choose to exercise the option of discontinuing the use of baseline systems. Similarly, the analyst may either use or delete the module which can provide information on the relationship of tasks to MOS and school boundaries. Other analyst options are provided by the clustering criteria which can be modified to reflect the type of new system being evaluated, whether operator or maintainer tasks are under consideration, and whether tasks are being aggregated into duty modules or duty modules into jobs. The analyst will be given the option of successively relaxing constraints after examining the product output (manpower personnel requirements in terms of number of jobs, soldiers required for each job and workload per job).

Of the processes accomplished by the product, that of task aggregation is the one which is accomplished in the least satisfactory manner today by a MANPRINT analyst making use of HARDMAN or MIST. (Essentially, these techniques are restricted in HARDMAN and MIST to a judgmental assignment of tasks to MOS.) Also, it would appear that there are more credible alternative approaches to task aggregation as compared to the alternatives available to the other major decision processes noted above. For these reasons this report will introduce the task aggregation approach earlier and will provide more discussion of alternative approaches to task aggregation -- as compared to the other decision processes.

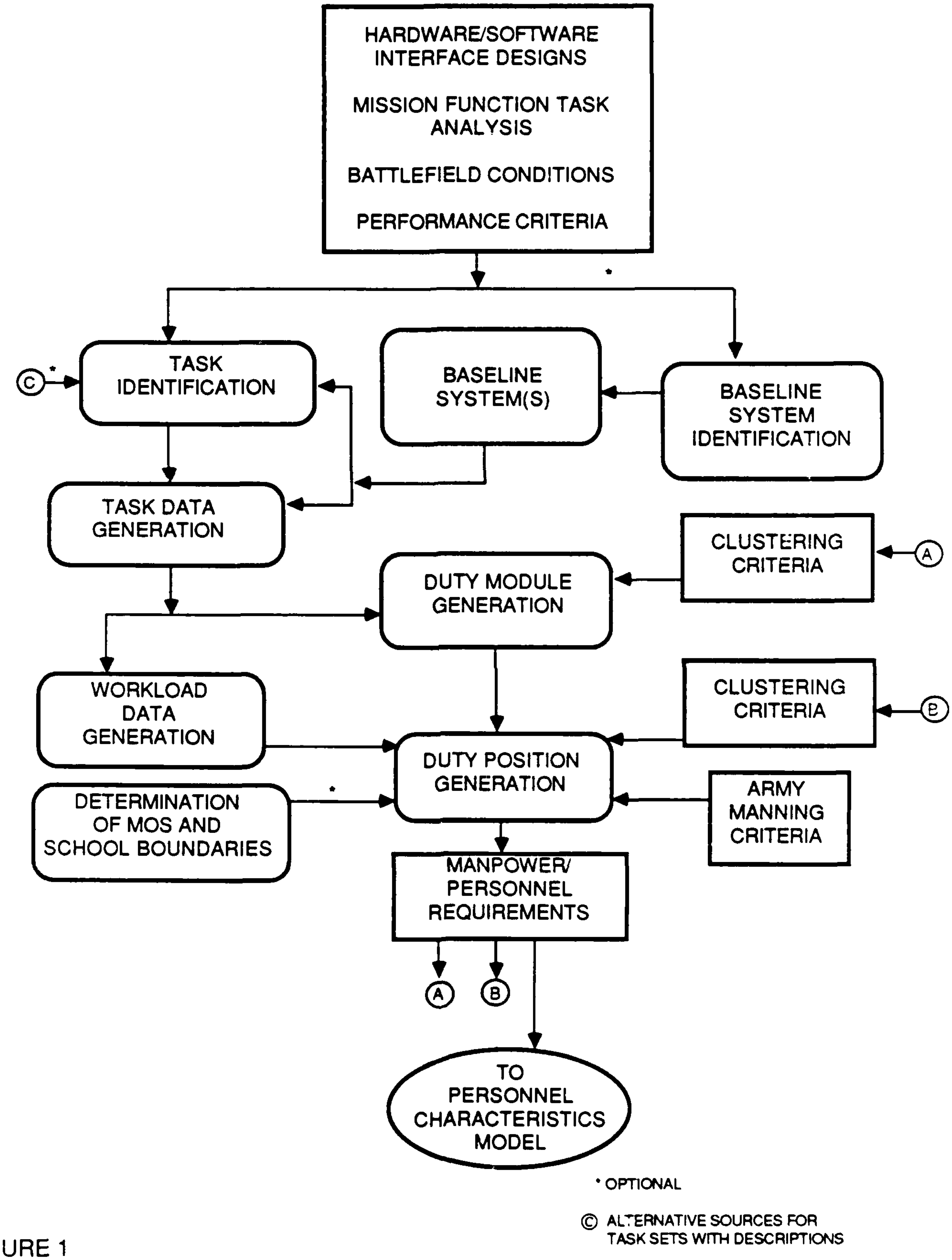


FIGURE 1
SCHEMATIC FOR PRODUCT FIVE

The Aggregation Process. The product decision aid proposed for implementation includes an approach to job component aggregation that can be compared to a linear programming model. This comparison is made in Figure 2. Job component interactions, relationships, organizational and supervisory boundaries, work locations, and other considerations can result in some mandatory combinations of tasks into task clusters and in the identification of other clusters that must not be aggregated. In the latter case, pairs of job components that are ineligible for aggregation with each other are recorded as zeros in a constraint matrix of zeros and ones. A measure of similarity among job components that bears on the utility of aggregating a pair of job components into a single cluster is referred to throughout this report as a S/U measure. This S/U measure compares with the objective function of a linear programming model.

The aggregation process, considered in context of other closely related processes and Product Five outputs, is summarized in Figure 3. This process will be much more carefully described later in the report. This summary is introduced at this point to aid the reader in his understanding and evaluation of design issues pertaining to the product when considered as a total system.

Broad Principles Shaping Design. In developing this design for the implementation of Product Five, emphasis has been placed on the following principles:

(a) The design will maximize the probability that Product Five can be successfully developed, installed, and utilized; the risk that the product will not achieve design goals will be minimized.

(b) The design will make use of all relevant variables; the selection of a convenient subset of variables -- convenient in that they are readily available, appear to be objective, or are amenable to simulation process, but which are not sufficiently representative of the variables that predict the desired utility measures -- will be avoided.

(c) An undue workload on the analyst will not be imposed by the design -- either by input requirements, or by the decisions required of the analyst.

(d) The bases of all Product Five decisions must be understandable to the analyst and he should be encouraged to use his intuitive expertise.

(e) The aiding provided to the analyst by the embedded decision models should reflect what a computer can do better than a human: assessing the data bank, the analysis of large numbers of comparisons, computations that are unwieldy or time consuming, and of course, all tedious clerical operations.

(f) The design will avoid the use of techniques that provide the appearance of objectivity and/or sophistication when these techniques fail to provide the real essence of objective data or

AGGREGATION MODEL

Analogy with a Linear Programming Model

Model	Linear Programming Model	Aggregation Model
Utility Function	Objective Function (Linear Definition)	Similarity/Utility Measure (Non-linear Cost Minimization; Cost Reduction Times (-1))
Constraints	Algebraic Definition (Usually expressed as a Set of Inequalities)	Rule Based (Task Interactions and Relationships Plus Organizational/Physical Taboos)
Optimization	The Objective Function is Maxmized (or Minimized) and a Constrained Solution then Sought, as in Brogden-Weaver Algorithm, or, as in Simplex Algorithms, Successively more Optimal Solutions, Each within the Constrained Space, are Sought	Only Mergers Meeting All Restraints are Considered; all Eligible Pairings are Tried Out with the Pair Which Maximizes the Utility Function Selected at Each Step. The Number of Job Components Under Consideration is Reduced by One at Each Iteration

FIGURE 2
Aggregation Model

DECISION PROCESS	OUTPUT TO PRODUCT SIX
a. Aggregate Tasks into Duty Modules Using Community of Required Competencies as the Simularity/Utility (S/U) Measure to Drive Clustering Process - within Constraints based on Organizational, Physical, and Time Restriction Task Relationships, plus other Task Interactions. Stopping of Clustering Process will Occur when S/U Increment is Below Threshold, when Number of Clusters has been Reduced to Predetermined Number, or Technological Complexity Exceeds Value set by Analyst.	Duty Modules Defined by Constituent Tasks and Task Descriptions.
b. Determine Workload Associated with Each Duty Module.	Not Applicable
c. Determine Duty Position/jobs and Recommended MOS to Each Job Using Aggregation Process Described in a. Above. Determine Manpower/Personnel Requirements by Job.	Jobs/Duty Positions Defined in Terms of Duty Modules; Recommended MOS for Each Job; Workload by Job; Manpower/Personnel Requirements in Terms of Jobs.
d. At Option of Analyst, Determine Current MOS and School Curriculum Boundaries as Related to Job Components; Redetermine Jobs, and Recommended MOS for Each Job - so as to Minimize Requirement for Changing MOS Structure and/or School Curriculum. Determine Manpower/ Personnel Requirements by Job.	Above Output, as in c. Repeated, but this Time also Considering MOS and School Boundaries (that in Turn Reflect Personnel and Training Availability).

FIGURE 3
The Aggregation Model Process in the Context of Product Five

measurement or when they fail to provide results which exceed the validity of results provided by less sophisticated (usually more understandable and less expensive to produce and use) methods.

Summary of Output. All tasks of the new system being evaluated will be identified in the final results as a component of a duty module and/or a job; in turn, each duty module and job will be identified in terms of its constituent tasks and the characteristics of those tasks.

An initial summary of Product Five output available for the use of Product Six (Personnel Characteristics) is provided by Figure 3. These outputs provided to Product Six in a machine-usable form will be available to the analyst with additional explanatory information, including information that will clarify the process that led to a particular output. Other intermediate outputs, as well as aids, prompts, and access to data bank, will be provided to the analyst to permit him to effectively control the process and to intelligently exercise the options permitted by the proposed design.

The number of manpower spaces needed to accomplish the defined jobs will be provided in the Product Five output. When exactly one manpower position is to be associated with each job (or duty position cluster of tasks), the number of jobs and number of required manpower spaces will be the same. In other instances, when the workload for a given task cluster is greater than that which can be accomplished by one person, for example, the number of "jobs" and the quantitative manpower requirements may be different.

Product Five will also provide the estimated number of personnel who must be in the Army inventory to achieve a reasonable assurance that the estimated manpower requirements can be met. These personnel estimates will make use of accepted relationships between manpower and personnel requirements, taking into consideration the various reasons that people in the Army inventory may be unavailable for performance in operational duty positions. The model will also calculate the estimated number of personnel who must be recruited and trained annually to compensate for expected losses from the required personnel inventory.

Summary of Required Input. It is understood that information bearing on task identification and description and baseline system identification (as required) will vary from little more than engineering drawings and specifications to well-defined task lists accompanied by HFE data on each task. The proposed product will permit the analyst to commence at either point without being called upon to redo something that already exists or being stopped cold because the available information is inadequate for initiating a task generation process.

The analyst will be required to input task lists with coded information bearing on task characteristics. Product Five will furnish recommendations and aid to help the user obtain this information and arrive at the required coding. (Since the information pertaining to the new system design cannot be counted upon to arrive in a standard format nor to arrive with a consistent degree of completeness, the analyst must still act as a transducer to convert design information into task data.)

The proposed product design includes a data bank containing files of competencies, MOS and school domain information. Data must be collected by the product developer and reviewed by Army school personnel during the product development phase. The development of this data bank will contribute to developmental cost, but will be rewarded by a considerable reduction in the demands made on the analyst.

BACKGROUND

The Army acquires systems as a mechanism for obtaining needed performance. The hardware and software components of most Army systems are operated and maintained by soldiers. Therefore, soldiers are components of those systems. The performance and availability levels of systems are directly related to the performance of the soldiers who operate, maintain, and support their hardware and software.

The levels of characteristics (aptitudes, strength, size, etc.) of people vary widely. Some levels of personnel characteristics exist in small percentages of the population that are not readily accessible to the Army. Usually, somebody can be found who (given enough of the right kind of training) can do whatever is required to operate or maintain even a badly designed system to required levels. Unfortunately, training resources are not infinite, and the effects of training on performance are not linear. The bottom line is that people who can do anything are in short supply and in heavy demand.

The Army needs to insure that its soldiers will be able to operate and maintain system hardware and software. It is particularly critical that soldiers who are available to the Army in required numbers be able to achieve with system hardware and software the levels of performance and availability that will permit mission success.

THE ACQUISITION PROCESS

Figure 4 illustrates the first part of the system acquisition process (through Full-Scale Development). The exhibit lists the major formal products and events which offer opportunities for Manpower, Personnel, and Training (MPT) input through Milestone II (ASARC and DSARC II). Organizational and Operational Plans may address organizational, equipment, and personnel tradeoffs required by inclusion of the system in the total force structure, providing input to the Tentative Qualitative and Quantitative Personnel Requirements Information (TQQPRI). The TQQPRI provides the most current information concerning the numbers and qualifications of personnel involved in the use, support, and maintenance of the proposed system. When appropriate and feasible, it describes duties and tasks, including work units, performance standards, recommended MOS, and other detailed factors. It may address implications for personnel selection and training support. The final version is prepared during Full-Scale Development. The Tentative Basis of Issue Plan (TBOIP) contains unit structure and issue recommendations which have implications for the numbers of personnel required by skill.

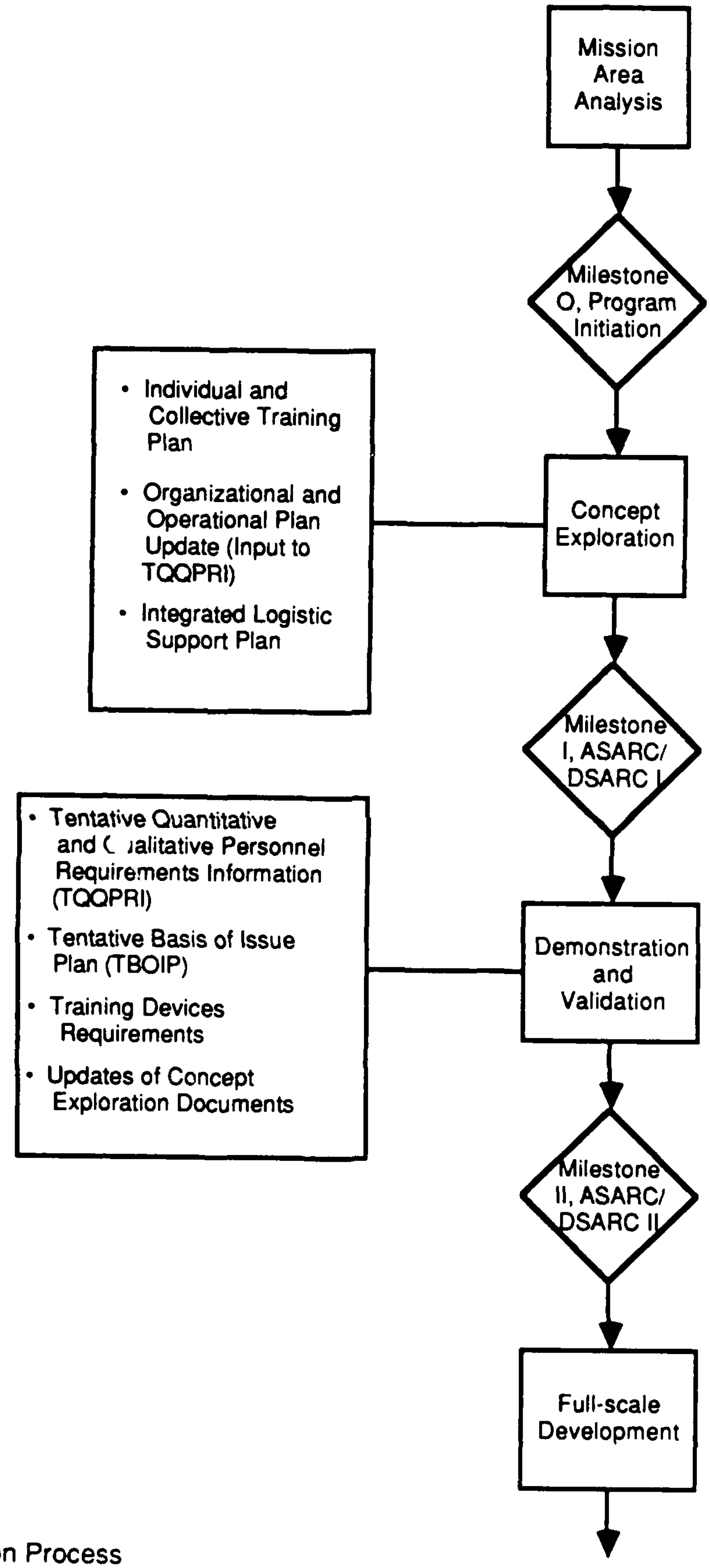


FIGURE 4
System Acquisition Process

By Milestone I, the major elements of the design which will derive the MPT requirements for numbers and skills of personnel are largely frozen. Later design changes can, perhaps, shorten training times or smooth rough edges of the design, but the basic structure of the user and maintainer tasks cannot be easily changed. MPT consideration is required prior to Milestone I in order to have sufficient impact on the system design.

As indicated in Figure 4, there are required documents which provide MPT design input prior to Milestone I. However, even when these documents are produced, the consideration of MPT factors is based largely on undisciplined subjective assessments; adequate data and analytic methodologies are not available. Furthermore, these requirements do not sufficiently influence the design. Some of the major reasons for this are:

(1) Personnel constraints are not provided in language and detail which the system designers (the PM office and the contractor) can understand and use;

(2) Designers do not believe they can afford to trade off machine performance to meet vague personnel skill limitations;

(3) In the source selection process the values assigned to Integrated Logistics Support (ILS) -- which includes MPT -- are low; and

(4) Performance competitions focus largely on the performance of the machine, not on the performance of the man-machine system.

ARI recently completed an ambitious project to analyze these problems and determine the implications regarding the acquisition process by performing "Reverse Engineering" on four specific systems: Blackhawk, MLRS, Stinger, and M-1 BITE. The major types of MPT problems found include the following:

(1) Human factors engineering was not addressed for some system components;

(2) O&O concepts were often incomplete or ill-founded;

(3) Manpower levels were underestimated;

(4) Skill and ability needs were undetermined or underestimated;

(5) Training concepts were untested; and

(6) Training devices were unavailable.

In summary, the problems fall into two areas. First, data and methodologies are not available to estimate MPT requirements adequately, in sufficient detail, and with sufficient precision to enable them to be enforced. Second, the mechanisms to manage the development and integration of this information are not fully in place. The aids to be developed in the present procurement address both these areas.

PRESENT METHODS

By virtue of its requirements and resources, the Department of Defense has been, on the leading edge of the development and application of new technologies. Weapon systems using these new technologies have been developed to upgrade or replace more traditional systems. New command and control and weapon systems are being developed to counter new high-technology threats from potential adversaries. Of all the armed services, the Army probably feels the greatest impact of the technological revolution we are currently experiencing. New battlefield command and control systems, computer-based combat operations centers, and complex, computer-based weapon systems are placing increased demands upon those who are the users of, maintainers of, and components in these increasingly sophisticated high-technology systems.

This continually increasing demand upon the Army's human resources, and a corresponding increasing awareness that the human may well be the limiting factor in ultimate system performance, has led to the development of several approaches to estimating the MPT requirements of systems in the materiel acquisition process.

One of these systems, the Army HARDMAN (from Hardware vs. Manpower) is a procedure for bringing hardware and manpower considerations into better balance. The Army HARDMAN Comparability Methodology was developed to provide credible MPT estimates early in the weapons system acquisition process (Zimmerman, Butler, Gray, Rosenberg, and Risser, 1984). The HARDMAN approach is adapted from that used by the Navy and involves comprehensive data collection procedures and intensive analysis of these data. After demonstrating its usefulness with four systems, the Army is institutionalizing HARDMAN into the acquisition process and is developing a guidebook for standardizing the methodology (ARI and SSC, updated).

MIST (Man-Integrated Systems Technology) in a sense represents a second-generation HARDMAN. Conceptually, it is similar to HARDMAN but utilizes more effective analytical procedures and automated data handling. It is anticipated that MIST will allow for: (1) reviewing the human element in a system from both a performance and a cost perspective throughout the system procurement process; (2) planning and forecasting of manpower information; (3) planning for an effective training system; (4) integrating human resource considerations into the test and evaluation process; and (5) providing for overall review of the status of human factors consideration in the system acquisition process.

Other techniques which have been developed or are under development for addressing the MPT issue are the Life Cycle Cost Model (HARDMAN Development Office, 1982) and the Training Requirements Determination Methodology (Pacer Systems, Inc. 1982), both of which have come out of the Navy HARDMAN office. The Early-On Manpower Requirements Estimation Methodology (EMREM) (Boden, Hutzler, Insley, McNichols, 1983) was developed through the sponsorship of the Department of Defense and attempts to determine "very early in the acquisition process, manpower demand over the life cycle of an individual weapon system." The Early Comparability Analysis (ECA) (Klass, Holzman, and Brandenbury, 1984) uses a variation of reverse engineering to identify problems in current systems so that they will not be repeated in future systems. The Army Tank Automotive Command has developed a comparability-based system for estimating

future system manpower requirements (Army Tank Automotive Command, 1982), (Bierly, 1984). Other approaches include the Job Assessment Software System (Rossmeissl, Tillman, Rigg, and Best, 1983) and the Comparison Based Prediction (CBP) methodology (Klein Associates, 1984), both of which attempt to estimate human resource requirements for proposed or new systems.

All of these techniques have contributed to providing MPT estimates early in the system acquisition process. The HARDMAN methodology has been an especially useful approach for both Navy and Army applications. However, improvements to existing approaches are both feasible and desirable. While the current approaches address some of the critical issues associated with providing timely MPT analyses, they all share, for the most part, some serious shortcomings, both theoretical and practical. Among the most serious shortcomings are:

(1) A focus on maintenance rather than operator performance,

(2) A near total disregard for skill requirements and soldier characteristics,

(3) An emphasis on training issues, and

(4) A foundation in comparability analysis.

The concept for Product Five in part overcomes these limitations. The Product Five concept also makes use of the best methods and procedures already developed in HARDMAN and MIST.

PRODUCT DEVELOPMENT

SYSTEM APPROACH STAGES

Army personnel make difficult decisions when developing information for evaluating design. The product development approach provides a finished product that aids personnel in making those decisions.

The development process is divided into three critical stages or tasks: (1) Concept; (2) Design Specifications; and (3) Production of Finished Products. Each stage or task has several critical issues that are addressed. As each task is completed, that task's deliverables (concept papers, design specifications, finished products) become the property of the U.S. Army. At the conclusion of each task, ARI evaluates the resulting concept paper, detailed design specification or finished product.

CONCEPT DEVELOPMENT STAGE

During Task 1, the concept critical issues were addressed and specified above in the concept paper objectives. As stated above, the goal of this report is only to report the results of this initial concept phase or task.

DESIGN SPECIFICATION STAGE

During Task 2, a detailed design specification of Product Five that describes operations, maintenance and training will be developed to establish the following:

(1) The required inputs of the product, its location, and how it will be accessed.

(2) The components of the product, where they will be obtained, and how they will interact.

(3) The process by which the product will produce its outputs.

(4) The outputs of the product, described in exact man-machine interface terms.

(5) The means by which computer files will achieve security.

(6) The means to insure organizational acceptance of the outputs of the product.

(7) The detailed schedule and estimate of costs for product development in 1986 dollars.

The design specification will be sufficiently specific that it will serve as the specification from which actual product development proceeds.

PRODUCTION OF FINISHED PRODUCT STAGE

During Phase or Task 3, the completed product (debugged as required) will be produced and provided. The product will be secure and will produce the required output for target users. The product will include the following:

(1) All required operational hardware (either obtained from the Army or purchased as required).

(2) All required operational software installed in the hardware.

(3) All required data either loaded into the hardware or directly accessible by the hardware.

(4) All required training software installed in the hardware.

(5) All maintenance documentation for hardware and software.

DATA REQUIREMENTS

PRODUCT FIVE

The following list of tasks which would be completely supported by an ideal Product Five provide the basis of the development goals of the concept being proposed for Product Five implementation:

(1) Define jobs and the workload for those jobs.

(2) Recommend MOS for each duty position.

(3) As appropriate, determine maintenance level of job.

(4) Determine workload information for periods of heightened operational tempo.

(5) Determine required capabilities in terms of content of tasks incumbents must perform.

(6) Provide computational algorithm for determining manpower requirements as a function of cumulative workloads; this algorithm will be consistent with those specified for Army use (e.g., AR 570-2).

(7) Make provision for analyst to iterate, changing inputs and/or constraints, to achieve convergence on required quantitative requirements outputs.

(8) Make provision for a quantitative clustering methodology compatible with Product Six - Personnel Characteristics requirements.

(9) Provide a basis for an early system design development decision regarding the acceptability of specific design alternatives (against manpower and personnel requirements).

(10) Assess impact of system design on MPT (quantitative) demands.

(11) Translate system characteristics into MPT demands.

<u>Essential Development Characteristics</u>. The proposed concept has the following characteristics as compared to HARDMAN and MIST (see Figure 5):

(a) Oriented toward the analysis and evaluation of specific candidate system designs -- as opposed to HARDMAN and MIST techniques of postulating a design based on mission and function analyses and comparability extrapolations.

(b) Oriented towards jobs, rather than towards MOS; to this end tasks will be aggregated into duty modules, and duty modules into duty positions; a job engineering capability will be provided.

(c) More provision for operator type performance including provision for task interactions; organizational, physical, and time constraints on

DESIGN GOALS FOR PRODUCT 5 AS COMPARED TO HARDMAN/MIST

- Oriented toward analysis/evaluation of specific designs, not postulated design.
- Oriented toward jobs, not MOS.
- More provision for operator performance, task interactions.
- Less concern with training resource estimation.
- More user friendly.

FIGURE 5
Product Five Compared to HARDMAN/MIST

the aggregation of tasks into jobs will be scrutinized for both operator and maintainer activities.

(d) Less concern with training issues such as the estimation of instructional hours, best training approach, etc.

(e) More user friendly with better prompting and aiding and less demand placed on analyst's skills in the domains of engineering and technology.

The proposed concept incorporates the following approaches to achieve additional capabilities (see Figure 6):

(a) Constraints on the aggregation of pairs of job components (i.e., tasks with tasks, tasks with clusters, and clusters with clusters) will have the first priority consideration in the clustering process.

(b) Commonality of required competencies (including enabling skills and more advanced task related skills across tasks) and task similarity (as measured by training transfer potential) will be considered in the aggregation of job elements into jobs.

(c) Provision for consideration of MANPRINT-relevant system design features in the estimation of workload will be made.

(d) Provision, as an option, for using estimated MOS and school boundaries in the process of aggregating job elements into jobs will be made.

(e) Practical interfaces with Product Six will be provided, to include: provision for identifying tasks, duty modules, and jobs for use in Product Six; provision for output of manpower and personnel quantitative requirements to Product Six; the provision of "what-if" capabilities for the exploration of job engineering alternatives for the alleviation of qualitative problems revealed in the results of Product Six.

DATA REQUIREMENTS AND SOURCES

MAJOR DATA CATEGORIES

Major data elements required for Product Five can be grouped into three distinct categories:

(1) Task identification and description.

(2) Task clustering criteria and measurements.

(3) Manpower and personnel management information.

NEW CONCEPTS FOR PRODUCT 5

- Constraints as first priority consideration in clustering.

- Consideration of enabling skills commonalities and training transfer potential (task similarity) in aggregation into jobs.

- Consideration of MANPRINT-relevant design features in workload estimation.

- Optional capability for consideration of MOS and school boundaries in the aggregation process.

- Outputs for input to Product 6, Personnel Characteristics Model.

FIGURE 6
New Concepts

Significant data requirements in each category and their sources are discussed below.

TASK IDENTIFICATION AND DESCRIPTION

The task and task data generation process for Product Five is described in the "Product Design" Section of this report. That section covers the process of task identification and generation of both qualitative and quantitative descriptions of the task as necessary for operation of Product Five. In contrast, the discussion below refers to the data which is obtained from external sources and used as input to the task generator.

Design Data. Information pertaining to system design is expected to vary widely in terms of form, precision, and completeness. The Product Five task generation process must be sufficiently flexible to accommodate the data which is available. Types of design data which may be available for task generation are as follows:

(a) Human Engineering Design Approach Document-Operator (HEDAD-O) and Human Engineering Design Approach Document-Maintainer (HEDAD-M). In normal acquisitions, the government requires the contractor to prepare these documents. Depending on the kind of acquisition process which the system being evaluated is undergoing, and on the status of system development, HEDAD-O and HEDAD-M will probably be available for use with Product Five. The detailed task descriptions contained in these documents can be used directly as the task identification and descriptions for Product Five.

(b) Logistics Support Analysis Record (LSAR). Again depending on the development status of the system design, the government may have required the contractor to prepare elements of the LSAR data package. These may have been among the deliverables required along with basic system design information. Alternatively, major positions of the LSAR, such as predicted reliability and maintainability (RAM) values, may have been required as part of a proposal for further system development. LSAR data contains both operator and maintainer tasks and a preliminary designation of the Military Occupational Specialty (MOS) and grade of the personnel who are to perform them. That is, like the HEDAD-O and HEDAD-M, the LSAR task information is the product of extensive task analysis by the system developer for the proposed design and should be used, when available, for determination of job requirements. (Such information and data should be critically examined before acceptance for Army use, but this is true of any design information produced by contractors.) LSAR or maintenance tasks are particularly useful for Product Five, in that each task is associated with specific components and quantitative data are provided. The quantitative data includes the frequency at which the task is expected to be required for both preventive (scheduled) and corrective (unscheduled) maintenance actions. The times required to perform each task are also given, in terms of elapsed time, the number of personnel, and the total maintenance man-hours required to perform each task. The task frequency and maintenance man-hour information

are readily combined to obtain the total maintenance workloads by task, by type and category of maintenance action, by system component, and by the system as a whole. If such LSAR data is available it should be used for determination of job requirements. For maintenance jobs, if LSAR data is not available, then similar quantitative task data providing essentially equivalent measures of frequency and duration must be obtained from other sources to compute total estimated workload and the consequent number of required jobs. One such source may be comparable systems which are already fielded.

(c) System Design Descriptions. Design descriptions in the form of drawings, narrative descriptions, mock-ups or other relatively early representations may be the only direct source of information on the new design. Often such descriptions can be used to infer the major operator tasks associated with the system, even if a detailed task analysis has not been performed. That is, the physical system design and the operational characteristics of system components often constitute sufficient information to allow explicit unambiguous definition of operator tasks, and even jobs. In such instances, operator job requirements may be established without further task clustering analyses.

General, non-quantitative system design descriptions are usually in themselves inadequate for the determination of maintenance job requirements. Since maintenance jobs are a function of the maintenance workload imposed by all components of a system, some estimated measure of maintenance task frequencies and corresponding task durations -- maintenance manhours -- must be available to determine the number of jobs and people demanded by the system. Measured data, appropriately adjusted, can be obtained from comparable fielded systems for which such data are available.

For both the determination of operator data and jobs, and the selection of comparable systems for maintenance workload estimates, a degree of subject matter expertise is required. If the Product Five analyst does not possess that expertise in the system being analyzed, then assistance from qualified Subject Matter Experts (SMEs) will be needed.

COMPARABLE SYSTEMS DATA

If quantitative workload data for the development system has not been developed in the form of an LSAR or a similar RAM data base, then it must be estimated, task by task, in order to determine maintenance job requirements. This estimate can be made using data from comparable systems for which data is available. Subject matter expertise will be needed in most instances in order to choose appropriately comparable systems. Comparability may be required in terms of mission, function, performance characteristics, and/or technology. Expertise is also necessary to extrapolate the maintenance workload from the measured values for comparable systems to estimated values for the new system. The extrapolation is based primarily on the estimated changes between old and new systems in terms of performance characteristics and technology. Changes in basic system function allocations must also be considered.

Data on comparable existing systems can be obtained from such sources as LSAR and the Sample Data Collection (SDC) program; data acquisition can usually be arranged through the cognizant project manager's office.

Comparable system data will be useful primarily for estimation of new systems maintenance workload and for subsequent maintenance job analysis. Although some insights into operator task analysis may be provided by comparable existing systems, operator task information in most applications will be derived primarily from direct analysis of the proposed new system design. As required, Subject Matter Experts will be needed to supplement the basic Product Five analyst.

TASK CLUSTERING CRITERIA AND MEASURES

Jobs are defined by Product Five as clusters of the tasks necessary for operation and maintenance of a system. The process for clustering the system tasks is governed by two general criteria. First, the clustering must conform to rigidly imposed sets of constraints; and second, the clusters which are formed must be better, by a quantitative, objective measure, than other permissible clustering patterns which are not chosen. The constraints, in turn, are of two general types. First, before any clustering activities take place, the provisions of a clustering-permissibility matrix are imposed. The permissibility matrix establishes whether each possible pairwise combination of system tasks is permitted or not. (In depicting the two-dimensional matrix, a "0" at the intersection of two tasks indicates they may not be placed in the same cluster, while a "1" indicates that such a clustering is permitted but not required. Hence, the matrix is often referred to in this report as the "0/1" matrix.) There is no provision in the permissibility matrix requiring any pairs of tasks to be clustered together; if such associations are considered mandatory, they are effected by combining them into a larger task -- a required cluster -- before inputting them into Product Five. Also, note that impermissibility is absolute. A zero in the permissibility matrix means that the indicated pair tasks cannot be in the same cluster no matter how many other tasks they might both be permitted to cluster with.

The second type of constraint employs certain threshold values to limit the extent of clustering of otherwise permissible pairings. That is, the number of tasks combined into a single job may be limited by threshold value limitations on the total workload involved, the multiplicity of required compentencies, or the degree of overall technical complexity which arises from task combinations. The paragraphs which follow discuss the data requirements and sources for the clustering process.

Task Interrelationships and Initial Constraints. The clustering permissibility matrix governing initial clustering constraints is developed by examination and analysis of tasks to ascertain which pairs of theirs cannot be placed in the same task cluster. Information for making these determinations is obtained through a task analysis conducted by the Product Five analyst and/or supporting SME's. Reasons for establishing impermissibility could include the following:

(1) Time and space relationships. When two distinct tasks must be conducted simultaneously and both require the full efforts of the performing individual, then obviously they cannot be assigned to the same job (same person). Similarly, two tasks which must be performed at nearly the same time but at relatively separated locations cannot be a part of the same job.

(2) System design and function allocation. The assignment of tasks to a particular job is often an obvious, inherent function of system design. Placement of controls and system monitoring components at the work station of an individual clearly intended to perform certain tasks amounts to a de facto clustering of those tasks into a particular job. This may be reflected by the Product Five analyst and/or SME as a larger, predetermined task cluster, and input into the permissibility matrix.

(3) Clear divergence of technological domains. Tasks may be so different in their technological makeup that allowing the clustering algorithm to investigate their inclusion in the same job would be an obvious waste of time and effort. In employing this rationale, however, the analyst must take care not to accept blindly a "traditional" way of looking at these issues at the expense of an objective analysis.

(4) Army policy. In a number of developmental systems, policy decisions regarding the number of certain jobs have been promulgated by the Army for incorporation in the designs, e.g., number of tank crewmen, number of helicopter pilots.

Initial clustering constraints via the permissibility matrix are considered far more likely to be applied to operator tasks and jobs than to maintainers. In many instances, operator job decisions will be possible even without identifying and describing the individual tasks involved. In these instances, the task analysis for generating input to Product Five would in part be required only for input into Product Six. (This assumes that a single task identification and description process can support both Products Five and Six, and that both products will be developed.) Some maintenance tasks may also be subject to clustering permissibility contraints, particularly constraints due to technological divergence.

<u>Clustering Measures: Competencies</u>. The primary objective function governing task clustering uses a measure designated as the Simularity and Utility (S/U) measure. This measure is derived from training parameters. The intuitive rationale for clustering a task with a given task or set of tasks, as opposed to all the others it could be clustered with, is some concept of similarity. Otherwise random clustering of any set of tasks not expressly prohibited from clustering would be as efficient and effective as a more careful approach. The measure of similarity chosen for Product Five is commonality of "competencies".

As stated above, the concept of competencies is an S/U measure. Briefly, competencies are the basic skills and capabilities which the operator or maintainer must possess to enable him to perform the higher order, more complexly structured system tasks. Examples of competencies are ability to

use a torque wrench, a multimeter, or complex electronic fault isolation equipment, or proficiency on a standard typewriter and computer keyboard.

It is possible for a constituent competency for a relatively complex task to be, in itself, a stand-alone task in a given context. A key characteristic of a competency as used in the S/U measure is that it be taught in Army Programs of Instructions, and that it is now or could potentially be common to more than one task.

The source for competency data is the Army training system, specifically, TRADOC schools. Insofar as basic enabling skills are already documented for Programs of Instruction, existing data in systems and tasks comparable to the new system can be employed by the Product Five analyst in ascertaining the competencies required for new system tasks. In the case of tasks for which comparable lists of competencies are not available, subject matter expertise must be employed to determine appropriate competencies. In many instances, the Product Five analyst will be capable of making such determinations without outside assistance, particularly if baseline system data files are available for reference. The architecure of Product Five will include the baseline files, but the cost of developing comprehensive competencies cross-referenced to a wide variety of existing systems will probably prevent their preparation as part of the Product Five development effort. Alternatively, the baseline reference jobs will be built in conjunction with successive Product Five applications.

Subject matter experts from the training community will be needed on a more frequent basis for determining competency training times. These training times are the basis for the Similarity and Utility measure which drives the clustering algorithm. Commonality of competencies among tasks causes a measurable decrease in the total training effort when those tasks are combined in a single job performed by the same individual, compared to training more than one person in the common competencies. The training time saved is a useful measure of the relative value of clustering choices, and if used would in fact cause a reduction in training times and costs. More importantly, however, the training-based Simularity and Utility measure was chosen because it is believed to express better than any other measurable factor the basic rationale for assembling system tasks into jobs.

The reference competency file to be included in Product Five will, when completed in successive applications, contain descriptors for accessing competencies. These descriptors, which include a school domain category, school and course title applicable to the competency, and a technology category, will be derived by the Product Five analyst from information obtained from Army schools. Training SME's will be required to assist the analyst.

<u>Baseline Systems Information</u>. Competencies required for a major portion of new system tasks will be determined through analysis of the tasks by the Product Five analyst, with assistance from system and training Subject Matter Experts. Determination of competencies for other tasks will be facilitated by reference to existing systems, tasks, and associated training courses. Therefore, provision will be made in Product Five for a Baseline System

reference file which will contain lists of competencies for selected existing systems. If funding levels permit, the constraints of the baseline file will be developed as part of the total Product Five development.

Descriptions in the Baseline Systems File are similar to those in the competency file. They include the baseline system name, the school domain categories for each set of baseline tasks, school and course titles which provide training in the baseline tasks, and the task technology category.

Information for the Baseline System File will be obtained from Army schools in the form of Programs of Instructions, Lesson Plans and other available course documentation. Training and baseline system subject matter experts will be required when system competencies are not explicitly associated with the tasks. Task data itself is available in the published training documents.

Technology Complexity Information. The Product Five analyst will be provided the option of considering overall job complexity levels in the process of clustering tasks into duty modules and jobs. A provision will be made in the clustering algorithm to limit the total complexity score of a job by setting maximum threshold values. Job complexity scores are the sum of complexity scores of the individual constituent tasks. Task complexity scores will be determined by the Product Five analyst. A decision aid will be provided in the product to assist the analyst; even with the decision aid, system SME assistance will be needed by the analyst, unless he possesses system expertise himself. (Similarly, training SME's and SME's of representative Army systems will provide input on the design of the decision aid, as part of the overall Product Five development.)

MANPOWER AND PERSONNEL MANAGEMENT INFORMATION

For Manpower and Personnel in Product Five, a determination of the manpower and personnel impacts of the job organization is implicit in the estimation of the number of jobs and the description of those jobs in terms of their constituent tasks. In fact, for maintenance functions, workloads and associated measuring criteria specified by the Army are the basis for determining the number of required jobs. Also, Product Five will provide an option whereby the current MOS and school structure of the Army can influence the task clustering process.

To obtain data for manpower and personnel management, manpower work capabilities have to be determined. Basic manpower requirements at various maintenance levels (e.g., organizational, direct support, general support) are determined by comparing the workload demands for a given job type with the available working hours of the maintainers. In current practice, workload and working hour availabilities are managed in terms of Military Occupational Speciality, but Product Five will not be restricted by those boundaries. Nevertheless, a comparison of required workload in terms of manhours and the Annual Available Maintenance Manhours (AAMMH) for various types of maintainers will continue to be the basis for determining the number of maintenance jobs required.

Required maintenance workloads are determined in Product Five by summing the workloads for each maintenance task included in a job cluster. Maintenance work availability data are obtained from Army Regulations 570-E, Manpower Requirements Criteria (MARC). MARC data is presented in terms of MOS. For most applications of Product Five, when MOS boundaries are not considered binding, the Product Five analyst will be required to select the most suitable values and computational rules from the regulation, based on the general category of maintenance action to be performed and on the type of equipment involved. SME assistance will be required only rarely, if at all.

<u>School and MOS Boundaries</u>. Product Five will be designed to allow the analyst to give explicit considerations to the current MOS structure as he controls the task clustering and job formation process. When the option to consider MOS is involved, a "preferred" MOS will be assigned to each task, based on the MOS which perform comparable tasks on existing systems. The analyst will also establish penalty values for clustering tasks with different "preferred" MOS. When an input total threshold penalty value is reached for a given cluster, further clustering across MOS boundaries cannot occur. Since the clustering algorithm selects the "best" clustering decisions at each iterative step of the process, the MOS boundary threshold prohibits the clustering of relatively less similar tasks, in an objective similarity sense, while allowing clusters of those which are relatively more similar.

Information to assist the analyst in assigning "preferred" MOS to tasks can be obtained from a number of sources. Army Regulation 611-201 provides a detailed description of each MOS. Task data for comparable systems, found, for example, in Logistics Support Analysis Records (LSAR) can also provide input, as can information from existing programs of Instruction (POI) for candidate MOS. In some instances, input from either system or training SME's may be useful, but such requirements should be minimal.

Penalty values for crossing MOS boundaries and maximum threshold values for prohibition of additional cross-boundary clustering will be established by the analyst. Product Five documentation will provide guidelines for establishing the values, but when the MOS boundary option is employed, the analyst must choose values which meet his particular analytical needs.

<u>Personnel Rates</u>. Existing methodologies such as HARDMAN and MIST (Man Integrated Systems Technology) are used to determine the number of jobs, or manpower <u>spaces</u>, for new systems. Similar information will be generated by Product Five. Specifically, the number of personnel which the Army must maintain in the inventory in order to fill the required manpower spaces will be estimated, along with the corresponding annual personnel inputs accessions, reclassifications) necessary to sustain the required inventory.

Rates with which to make personnel estimates are readily available. The U.S. Army Military Personnel Center (MILPERCEN) regularly publishes the DAPC-238 report containing historical - MOS Trainee, Transient, Holdees and Student (TTHS) rates. These can be used to translate manpower (spaces) requirements into requirements for personnel (faces). Both MILPERCEN and the Defense Manpower Data Center (DMDC) have personnel flow rates, such as losses and promotions, which can be used to determine the requirements for annual personnel input to sustain the required inventory.

CLASSES OF INFORMATION

ARCHITECTUAL DESIGN

<u>Modules and Module Components</u>. The modules of the proposed concept implementation are depicted in Figure 7. These modules can be loosely defined in terms of the decision aids and models utilized, the data bank files accessed and the working files created or accessed. The decision aids and models will be embedded in a common software environment. This environment and the aids and models together will be referred to as a model bank. The model bank, the data bank, the working files, and user interface software will comprise the computer aided components of the concept implementation of Product Five.

The term data bank will be used in this report to refer to the set of information files created during product development for the purpose of residing permanently in the product and which are supported by user friendly retrieval software (embedded in decision aids) and is utilized in a decision making and working file generation in conjunction with one or more decision aids. Some data bank files will have provision for having additional records added by the analyst. Working files created entirely by analysts may also be retained and optionally accessed at a later date, but such files are not considered to be part of the data bank.

<u>The Data Bank and Working Files</u>. Whereas the data bank files will be integral to the product, existing prior to the first use of the product by an analyst, the working files come into existence as a result of the analysts efforts with respect to a specific new system under MANPRINT evaluation. The working files provide the means of passing information across modules, to the analyst, and finally to Product Six. Thus, the working files provide the thread that ties the modules, and their decision models and aids into a single integrated product.

The task description file is comparable to a undirectional data bus; each module, commencing with task identification and continuing through manpower and personnel requirements, uses and adds to the task records of this file. The job component (cluster) file may have many trial versions but will have a continuing existence in some form from its creation during duty module generation on to the point where final output files are prepared. Some working files will be accessed only within the module where they were initially produced. Such local files have the function of organizing and recording (documenting) the analysts efforts in creating other files which do cut across module or product boundaries.

The data base will contain four distinct files. The one of greatest importance will be referred to as the "competency file". This file is the source of information on the utility resulting from two tasks having various degrees of commonality of competencies.

Competencies include enabling skills, such as use of a torque wrench or multimeter, but also include more advanced skills and knowledge that can be expected to be required by a number of tasks that are similar -- in that they share a requirement that the incumbent have this more advanced competency. An

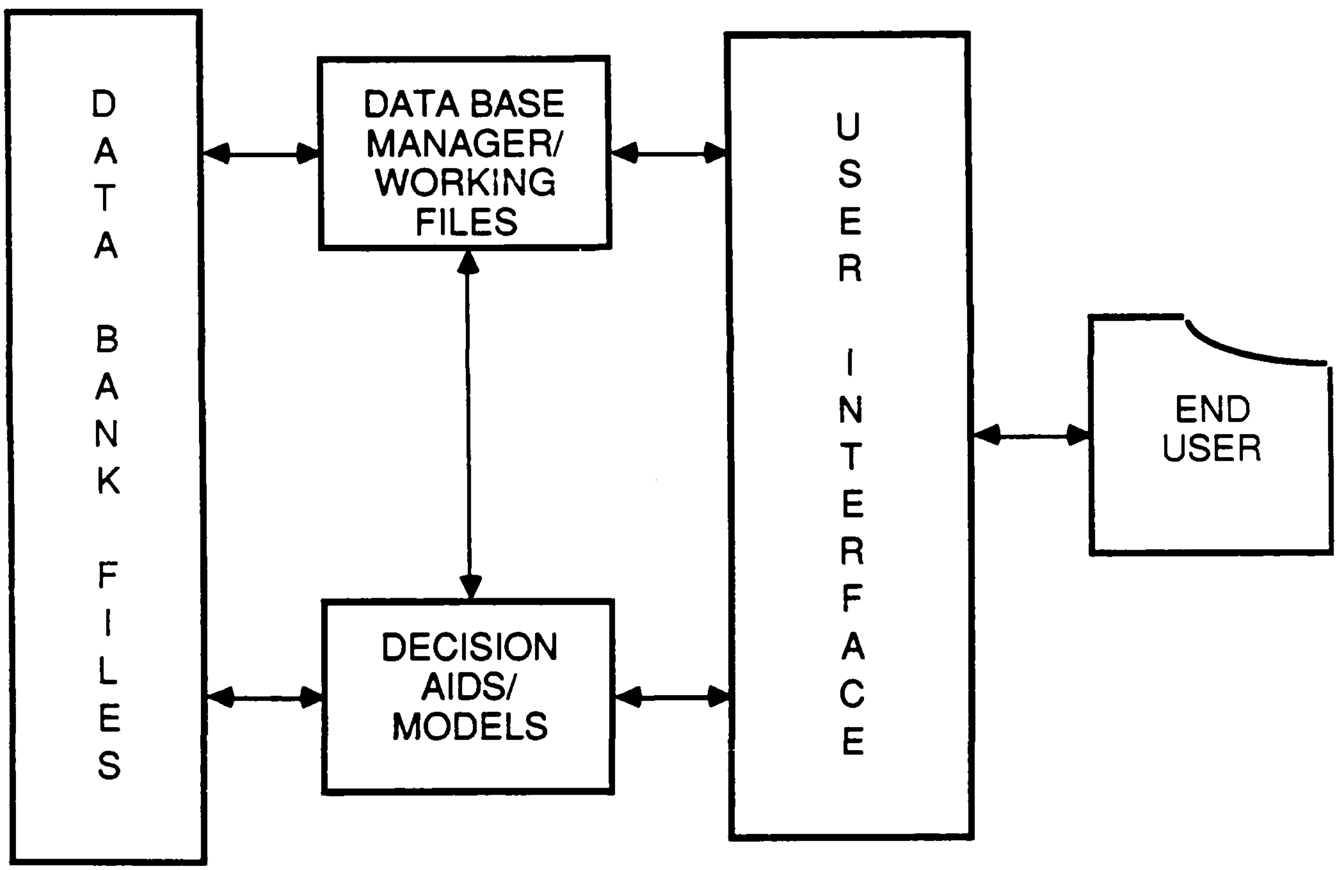


FIGURE 7
Product Five Design

example of such a more advanced competency is provided by the knowledge of triangulation methods necessary for two different operators' tasks -- one in which the height of nearby trees must be accurately estimated -- and another task in which the distance to a known location must be estimated. Each competency record has several descriptors, the compentency title (phrase), and the value of not having to train a soldier in this competency (time to train and maintain). This data base content must be collected, largely from Army school doctrine and experience, as part of the Phase 3 product development process.

The second data base file will be referred to as the "baseline systems file". This file will have the same three descriptors as the "competency file". These descriptions fall into three categories: 1) a coded technology category, (2) a coded school domain category, 3) system and subsystem category, and mission type. Each record will have a baseline system title, proponent of system operation (for the baseline system relevant to the operator), and proponent of system maintenance (for the baseline system relevant to the maintainer), and identification of relevant soldier's manuals, in addition to the descriptors. The information for this file is obtainable from school POI and other course documentation and/or from the proponent school's Combat Development (CD) organization.

The third data base file will be referred to as the "MOS and School Boundaries File". That file will include the description and much of the information contained in the other data bank files structured in such a way as to permit the exploration of MOS and School Boundaries with respect to each task.

The Model Bank: Decision Models and Aids. The models and decision aids, with associated data bank or working file(s) are organized by the modules depicted in Figure 1 and 7 and listed in Figure 8. These models and decision aids will be separately considered in section titled "Module Logic and Processes". Our concern here will be with the overall process and the flow of information and results from the first to the last of the modules.

The distinction in this report between the designation of decision aiding software as decision models, as contrasted with being referred to simply as decision aids, is based on the presence of significantly more information analysis algorithms in the models as compared to decision aids. Those designated as models also contain several submodels and decision aids, and provide the analyst with recommended solutions -- as contrasted with the support of the analysts own organizing, recording and decision process provided by those designated as decision aids. All working files are supported by a decision aid, but sometimes (e.g., with respect to the "constraint categories file"), a working file is essentially a scratch pad and a provider of documentation for a decision aid.

There are four decision models in the concept design proposed in this report for specification and implementation in phases 2 and 3. These models are as follows:

Product Five Models & Decision Aids
(Figure 8)

Short Description of Model/Aid	*Module (See Fig. 1)*	*Input (Working) Files*	*Data Bank Files Accessed*	*Output (Working) Files*
Identification of Baseline System Candidates	Baseline Systems Identification	None	Baseline Systems File	Baseline Task File
Selection of Baseline System Tasks	Baseline Systems	Baseline Task File	Baseline Systems File	Baseline Task File
Identification of System Tasks–aids and prompts for determinig technology/subsystem descriptions and for effecting DB file access.	Task Identification	Task Working File; Baseline Task File	Baseline Systems File; Compentency File	Task Working File
Accomplish separately by task: 1) a basic task description 2) the selection of a compentency set 3) review training hours assigned to compentency in DB file	Task Data Generation	Task Working File	Compentency File; MOS and School Boundaries File	Task Working File
Aids and prompts for assigning importance weights to competencies with repect to each task.	Task Data Generation	Task Working File	Baseline Systems File; Compentency File	Task Working File
Aids and prompts for selecting D/Cs and the assigning of technology complexity scores to each D/C within each task.	Task Data Generation	Task Working File; Baseline Task File	D/C File	Task Working File

Product Five Models & Decision Aids
(Figure 8 Continued)

Short Description of Model/Aid	*Module (See Fig. 1)*	*Input (Working) Files*	*Data Bank Files Accessed*	*Output (Working) Files*
Aids and prompts for: 1) Selecting and determining generic tasks. 2) Assigning training transfer effects to generic tasks.	Task Data Generation	Task Working File	Compentency File	Task Working File
Aids and prompts for reviewing task characteristics and the creation of the 0/1 constraint matrix.	Task Data Generation	Task Working File	None	Task Working File
Aggregation Model (See Figures 11 & 12).	Duty Module Generation; Duty Position Generation	Task Working File	MOS and School Boundaries File	Task Working File
Workload Model: Aids, prompts, computing aids, and recording, formatting aids for generating task and duty position workload data.	Workload Data Generation	Task Working File	None	Task Working File
MOS and School Boundary Model: C/Ds associated with each task are used to access DB file and compute boundary violation score for each task.	Determination of MOS and School Boundaries	Task Working File	MOS and School Boundary File	Task Working File
Manpower/Personnel Requirements Model	Manpower/ Personnel Requirements	Task Working File	None	Product 5 Output File

(1) Aggregation Model,
(2) Workload Model,
(3) MOS and School Boundaries Model,
(4) Manpower and Personnel Requirements Model.

USER AND SYSTEM INTERACTIONS

Menu of Models and Decision Aids. The analyst can call up a menu of decision aids and models at any point in his analysis. He can use anything on the menu provided the working file required as input is at an adequate stage of preparation, or he is willing to provide the data and create the required working file. This permits the analyst to perform what-if analyses with hypothetical data if he so desires.

The Sequence of Events. The analyst is in complete control of the sequence of events while using Product Five. To that end he must start each model and decision aid; there will be no automatic communication across decision aids and models. All communications across decision aids and models occur through the use of working files that are subject to review and modification by the analyst. Some decision aids have the primary function of creating or adding to working files while others may use one working file created elsewhere as input and create another working file as an output. The Product Five software shell will assure that the appropriate working files are used as input and/or output by each decision aid and model across, as well as within modules.

The Alternative Sequences. If the analyst has alternative sources for task sets and task descriptions, and does not want to first generate duty modules he may follow the following sequence of modules (from figure 1):

(1) Task Identification
(2) Task Data Generation
(3) Workload Data Generation
(4) Duty Position Generation
(5) Manpower and Personnel Requirements

The more usual sequence, with less information about tasks at the beginning and a need to more carefully define jobs, involves the following module sequence:

(1) Baseline System Identification
(2) Baseline Systems
(3) Task Identification
(4) Task Data Generation
(5) Duty Module Generation
(6) Workload Data Generation
(7) Determination of MOS and School Boundaries
(8) Duty Position Generation
(9) Manpower Personnel Requirements

The analyst may review the results from step 9 and reset clustering criteria in order to iterate through steps 5 through 9 again.

MODULE LOGIC AND INTERNAL PROCESS

Task Identification and Task Data Generation. The basic relationship between the design of a new system and the jobs and people to operate and maintain it is defined by the human tasks involved. Product Five formulates jobs, and determines the required number of them, by clustering the human tasks in a rational, systematic manner. System operation and maintenance must therefore be defined and described in such a way as to allow the clustering algorithm to operate. Basic task definition and description requirements are given below:

- Task name.
- Task type, operator or maintainer.
- Word description, in sufficient detail to enable understanding of what must be done with each subsystem or component of the system. This description must support analysis for determination of the competencies associated with the task.
- Information describing the relationship of the task to other tasks. Primary relationships will be in terms of time and/or distance. Such relationships will be significantly more important for operator tasks than for maintainer tasks.
- Quantitative information on maintenance task frequencies and durations. This data is necessary for the computation of maintenance workloads, which in turn are used to determine the required number of maintenance jobs.

Sources of task data are discussed in detail in "Data Sources." Essentially, task data are derived both from analysis of available design information for the new system and from data available for comparable existing systems. Descriptions and data for both operator and maintainer tasks will be derived from new system design information, but this design information is of overriding importance for operator tasks. Unless there has been extensive maintenance task analysis, as reflected in the Logistics Support Analysis Record (LSAR) or similar Reliability and Maintainability data, a primary source for qualitative and quantitative maintenance task descriptions will be existing systems which are comparable to the new developmental system. If a Human Engineering Design Approach Document - Operation (HEDAD-O) and/or a Human Engineering Design Approach Document - Maintenance (HEDAD-M) are available, they will constitute a prime source of task data.

Methods for generating task data will depend on the degree to which specific design data is available, and the extent to which these data reflects any previous task analyses by the system developer. If extensive task analysis have been performed, to include task sequence analyses for operators and frequency and duration determinations for maintainers, then essentially no additional task generation will be required for Product Five. More likely, only incomplete task information will be available to the analyst. In that case, all available design information (including drawings, narrative system descriptions, function allocations, and performance characteristics) will be used to generate system tasks.

When operator task analysis results are unavailable, task information must be generated from other sources. The primary source will be new system design information augmented as necessary by task data on existing comparable systems. Task descriptions will be derived by examining the operation of the new system in detail and drawing logical inferences regarding the function of the human component of the system. For example, the design of a target acquisition device will essentially define the actions which the operator must take to use it, as will the design of a vehicle's steering, braking, and speed control systems. Examination of the design of the various components of a crew-served system and their functional interactions during operation will define the required crew tasks and their sequence. In instances where the design is unclear, comparable system tasks can be used to assist and augment the analysis of new system tasks.

The determination of operator task information which is otherwise unavailable will be accomplished by the analyst who is applying Product Five. In the likely event that he is not expert in the design of systems similar to the new system, assistance from SME's will be required.

Identifying and describing maintenance tasks for a new system require a process which is significantly different from that for operator tasks. While basic system design information allows determination of operator tasks, and often direct determination of operator jobs, maintenance information can seldom be directly derived. Unless one is thoroughly expert in the technology, there is virtually no way to ascertain the reliability and maintainability of complex systems by examining the plans for their design. The direct identification and qualitative description of maintenance tasks would itself be a formidable effort, but quantitative descriptions would be essentially impossible.

To overcome the difficulties of direct maintenance tasks analysis, the Product Five analyst will utilize task data from comparable systems. The functions, performance characteristics, and technology of the new system will be analyzed and matched as closely as possible by systems, subsystems, and components of existing systems for which maintenance data is available. The data will then be extrapolated judgmentally to reflect as accurately as possible the difference between the existing and new systems. The resulting quantitative and qualitative task descriptions are used in the Product Five task clustering and job definition process.

Interpretation of possibly incomplete system design information, identification of comparable systems, and extrapolation of quantitative and qualification task data from existing to future systems requires an appreciable measure of system expertise. If the Product Five analyst is not reasonably expert in the type of system being analyzed, the assistance of a system Subject Matter Expert will be required.

<u>Aggregation of Job Components</u>. The provision of an overriding priority to the eligibility of job components for combination with other components in the making of task aggregation decisions was considered to be essential. It is further desirable that these eligibility considerations be made explicit to the analyst with a clear option for the lifting of each separate constraint on eligibility made available at appropriate decision points.

Since further aggregation decisions, within the restrictions imposed by the eligibility considerations, will be made on the basis of a Similarity and Utility (S/U) measure, it is desirable that the variables determining eligibility and the variables contributing to the S/U measure be logically independent. Most of the eligibility considerations differ from those contributing to the S/U measure in that they are readily expressed as binary variables. After compulsory aggregations of job components are implemented, the relationships among the remaining components can be expressed in a zero/one matrix where a one indicates that aggregation is permitted and a 0 indicates that aggregation of that pair is prohibited. However, other variables relevant to the clustering process that less clearly take on the values of must, must not, or permissiveness may still be placed in the constraint variable (eligibility) category if they also do not readily take on a value along a continuum of utility variable values. Those variables which make an independent contribution to the clustering decision, but do not have a logically clear relationship to the S/U variable, must be considered in the context of the constraint matrix.

The eligibility conditions expressed in the constraint matrix should reflect what experts consider to be mandatory rules when they undertake a process of defining duty modules or jobs from tasks. These eligibility variables should also reflect supervisory decision criteria used to group tasks for assignment to individual subordinates.

The Role of the Constraint Matrix. Tasks will have been coded (within the Task Data Generation Module) with respect to characteristics that indicate strong indications for either combining or not combining pairs of tasks, or conversely, indicate the permissability of combining a given pair of tasks. Criteria for making this determination are summarized in Figure 9. Inseparable tasks are immediately aggregated into task clusters making it possible to represent in a constraint matrix all pairwise eligibility determinations among job components (task, or task clusters) as a 0 (prohibited) or a 1 (permissable).

Whenever a pair of job components (either tasks, task clusters, or task and cluster) is aggregated to form a single component the order of the constraint matrix is reduced by one. The boolean "and" operation on the two constraint vectors being merged into one provides the new 0/1 row and column vector representing the new combined job component. All other vectors in the matrix remain the same.

The degree of connectivity found in the constraint matrix may be so high as to leave most of the clustering decisions to considerations of the S/U measure. Most maintainer activities may fall in this category. Conversely, many operator activities may yield a constraint matrix of such low connectivity that no flexibility for further clustering with the S/U measure remains. Thus, an immediate feedback of the maximum and minimum number of clusters permitted by a constraint matrix will then provide the analyst the option of proceeding to the workload determination module and then returning to the Duty Position Generation Module to accomplish all further clustering decisions using the 0/1 constraint matrix and the workload aggregation matrix. The alternative to this option is to proceed to the aggregation step that utilizes the S/U measure.

CLUSTERING CRITERIA

AGGREGATION ELIGIBILITY

- Task Interactions/Relationships

  -- Simultaneity
  -- Appropriately Time Shared
  -- Prerequisite Relationships
  -- Inseparable Tasks Form A Single Job Component

- Organizational/Supervisory Structure

  -- Analyst must define and code categories

  -- As controlled by analyst, clustering prevented across organizational lines.

- Physical Constraints -- Location, Barriers

  -- Analyst defines/codes each task for separated work areas.

  -- Aggregation of separated tasks prevented.

- System/Technology Category

  -- "Doctrine" on inseparability of responsibility for system/subsystem components.

  -- "Doctrine" on inseparability of mission/function components relating to tactical objectives.

  -- Inseparable tasks Form A single job component.

FIGURE 9
Clustering Criteria

The analyst has the additional options (in addition to those offered by the setting of constraints to form the 0/1 matrix) of prohibiting aggregation that exceed threshold values set by the analyst for the following variables:

(1) Workload Sum for Each Cluster
(2) Technology and Training Complexity
(3) Extent MOS and School Boundaries Are Violated

Each of the above three constraint variables can be computed and considered each time a pair of job components is selected as yielding the maximum value for the S/U measure. If the aggregation of a pair is prohibited because a threshold value set by the analyst is exceeded, the 1 is changed to a 0 in a working copy of the 0/1 constraint matrix, the aggregation is not accomplished, and the pairwise hunt for the maximum value of the S/U value for eligible pairs continued.

These three constraint variables are of interest to the analyst for the following reasons:

(a) The workload sum for each cluster must be below a specified number in order for it to be considered as a job for one soldier.

(b) The technology and training complexity value (essentially a by product of the computational process that yields a value for a S/U measure) should not be too high because of implications for personnel qualitative requirements.

(c) The extent MOS and School boundaries are violated should not exceed an amount that the analyst believes can be tolerated without disruption of either the personnel or training system.

The S/U Measure. An ideal S/U measure would incorporate all the factors an expert considers in the allocation of tasks to jobs in the construction of a TOE (or a TDA), in the defining of a new MOS, in the determination of requirements during a manpower survey, or in a hypothetical situation in which a job engineering process of rearranging duty modules within a set of jobs to increase efficiency is being undertaken. Such an ideal S/U measure, if maximized in a clustering process, should agree with the decisions a true expert would make if he had the mission and time to conduct a careful consideration of all system tasks and to cluster them into jobs. Actually, the S/U measure used in this product is utilized to make decisions within the space remaining after the 0/1 constraints have been applied, and also need not duplicate the measurement domains of the three additional criterion variables for which threshold values may be (optionally) assigned. Thus, the factors the S/U measure should cover are considerably reduced. In summary, the ideal S/U measure should reflect what experts would consider, above and beyond the implications of: (1) the 0/1 constraints, (2) technological complexity, (3) school and MOS boundaries, and (4) workload distribution.

An ideal S/U measure would also reflect supervisory decision criteria in grouping tasks for assignment to individual subordinates. Again, our S/U measure should be relatively orthogonal to the variables included as

constraints to form the 0/1 matrix or used as threshold criteria in determining whether a selected merger will be allowed to stand, while incorporating the remaining variables considered by the supervisor.

The major considerations not already covered by the constraint or criterion variables cited above would most likely include the need to maximize the probability that an incumbent can be selected who can perform satisfactorily on all tasks assigned to him, and to maximize the reduction of training effort and cost. There is a definite utility in the selection of two tasks for merger into a job (for an individual) when the probability is high that an individual who can do one task well can also do the other well. Similarly there is a high utility for merging a task into an existing cluster of tasks when the task to be added brings no new competencies to be learned by the incumbent.

To be acceptable the S/U measure must clearly comprise an objectively determined utility function. It must have an easily understood metric on which to measure similarity of tasks in terms of a scale that is directly proportional to the increase or decrease of utility. The metric should be at least an interval scale with some of the features of a ratio scale (with a true zero). An ordinal scale is definitely not acceptable. It must be possible to measure the relative utility of adding a job component to each of the other components and to identify the pairing which would provide the greatest utility, and to compare the utility of that optimal merger to the utility that would result from leaving the two job components unmerged (as candidate duty modules or jobs). The above criteria for selecting a S/U variable are summarized in Figure 10.

It is essential that a S/U measure not require unreasonable demands on the analyst in terms of either his ability to make judgments or of his time. Thus, while the analyst is required to make decisions and to provide coded input at the task level, he is not required to make judgments on task pairs (or worse yet on task sets of 3, of 4, etc.).

The algorithm appropriate for computing an S/U value associated with a possible merger of two job components is dependent on the nature of the S/U measure. Thus it is essential to choose a S/U measure that will permit an economical comparison of all candidate mergers--with the additional calculation of S/U values at each iterative step kept at a minimum. The S/U measure must be meaningful, and fully comparable across job components containing widely different numbers of constituant tasks, in order to permit an iterative algorithm based on making pairwise comparisons.

The S/U measure must have a clear relationship to an underlying measure of utility to the Army. To this end, the S/U measure must not involve the combination of two or more variables, unless all the variables are expressed in a common metric (such as dollars, training time, predicted standard performance, etc.) that will be retained in the combination process. The use of arbitrary weighting of such diverse variables as workload, technological complexity or functional similarity to form a utility function is especially to be avoided.

CLUSTERING CRITERIA

DEFINITION OF THE S/U VARIABLE GOALS

- Reflect experts' criteria in defining duty modules, jobs.
- Reflect supervisors' criteria in grouping tasks for subordinates
- Clearly compromise an objectivity defined utility function.
- Credible similarity, utility scale
- A direct relationship between the similarity between two tasks and utility to the Army.
    -- Probability that if soldier can accoplish one task he can accomplish the other.
    -- A reduction in the training effort and cost for one task if he is proficient in the other.

FIGURE 10
Definition of the S/U Variable

As stated above, it is highly desirable that the scale on which the s/u measure is expressed provide for at least internal scale relationship. The scale should have the capability of meaningfully expressing a difference between the utility of two alternative mergers in terms of the increments resulting from a merger as compared with the utility of leaving each merger candidate unpaired -- even when one alternative pairing is at the high end of the s/u scale and the other alternative is at the low end. The one yielding the largest increase in s/u value resulting from the merger will be selected. The use of this kind of algorithm obviously requires a highly sophisticated scale. The provision of only an ordinal scale in the s/u measure would require the use of a different algorithm for selecting an "optimal" pair of job components for aggregation.

The s/u measure used for Product Five will be considered at three levels of sophistication. At all three levels the s/u measure is expressed in terms of the hours required to train an incumbent to perform the job component. The s/u measure increment is the gain in reduced training time resulting from a merger of two components as compared to the training time required if both components were kept separate and assigned to different incumbents. That increment is made to be positive by multiplying a negative difference by (-1); it is then maximized by selecting the pair of job components that yields the greatest gain. Each successive merger also maximizes the gain that is obtainable at that iteration. Since the order of the s/u value matrix and the 0/1 constraint matrix are both reduced by one during each iteration, the process, if not stopped for another reason (e.g., because no more eligible pairings exist) would eventually reach the point where only two job components remain to be compared. The variables defining the s/u measure at Level 1 remains the most important consideration at Levels 2 and 3. Similarly, the Level 3 variables are added to the Level 1 and 2 variables for the more sophisticated Level 3 concept. The variables to be introduced at each development level are summarized in Figure 11 and Table 1.

The competencies required for the accomplishment of a task are identified by the analyst during the Task Data Generation Module. Candidate competencies corresponding to descriptors input by the analyst are retrieved from the data base. When a list of competencies have been selected for a task, additional information is drawn from the data base, including initial training time and training maintenance time associated with each competency. Competencies consist of both enabling skills and more advanced task related skills that cut across two or more tasks. Generic tasks described so generally that tasks within a family of such tasks could be defined by adding more specificity can also be named as competencies. The time required to

CLUSTERING CRITERIA

DEFINITION OF THE S/U VARIABLE

SELECTED S/U MEASURE

Function of:

- Commonality of competencies (Level 1)
- Similarity of tasks in terms of amount of training transfer (Level 2)
- Learning decay rate (Level 3) Importance of each competency to achievement of task objectives (Level 3)
- Frequency of task performance (Level 3)

Metric:

- Expressed in terms of training hours for:
  - -- Initial training
  - -- Training maintenance

FIGURE 11
Selected S/U Measure

TABLE 1

COMPARISON OF THE S/U MEASURE ACROSS DEVELOPMENTAL LEVELS

DEVELOPMENTAL LEVEL	SUMMARY OF S/U MEASURE	VARIABLES CONTRIBUTING TO S/U MEASURE
1	INITIAL TRAINING HOURS TO PROVIDE COMPETENCE REQUIRED BY TASKS	COMPETENCE
2	DEVELOPMENTAL LEVEL ONE S/U MEASURE --WEIGHTED BY IMPORTANCE TO THE ACHIEVEMENT OF TASK STANDARDS-- MINUS TRAINING TRANSFER EFFECTS	COMPETENCE TRAINING TRANSFER IMPORTANCE WEIGHTING
3	DEVELOPMENTAL LEVEL TWO S/U MEASURE PLUS TRAINING HOURS CONTRIBUTING TO TRAINING MAINTENANCE	COMPETENCE TRAINING TRANSFER IMPORTANCE WEIGHTING LEARNING DECAY RATE PERFORMANCE FREQUENCY

train the more advanced competencies will be based on assumptions that competence in all prerequisite enabling skills is present.

The S/U value for a job component is the sum of the training hours associated with each competency required by that job component (a task or a cluster of tasks). When two job components are merged their competency sets are combined into a common set and duplicates removed. The S/U value for the new job component resulting from the merger (aggregation) is again the sum of the training hours associated with each competency required by that job component.

The S/U value for a candidate merger of every pair of job components will be computed initially and again for each new row added to the S/U value matrix. A new row will be added each time two rows, corresponding to two components being aggregated, are deleted and the new merged job component added to the matrix. Thus, only one row of S/U values need be computed at each iteration in which a merger is effected.

The selection of the "best" pair of job components for merger during a given iteration will be made on the basis of a difference defined as the training hours of one job component plus the training hours of the other job component minus the training hours of the merged job component. When multiplied by (-1) this difference becomes the gain increment which is maximized at each iteration of the aggregation process.

Functional Definition at Developmental Level 2 permits the consideration of: (1) the importance of each competency to the accomplishment of task standards, and (2) the use of generic tasks in terms of training transfer effects rather than as required competencies. The Product Five developmental cost would increase very little if it is decided to advance to level 2, however both level 2 features require additional analyst judgments and his time to input this information during the Task Data Generation Module.

The importance of each competency to the accomplishment of task standards would be used as weights for computing the weighted sum of training hours each time a S/U value is computed by the product. This feature would increase the face validity of the S/U measure by making this measure more directly related to task and system performance.

To incorporate into the S/U measure the training transfer effects that similar tasks provide for each other, the analyst would define one or more generic tasks that reflect the perceived similarity relevant to training transfer across a number of tasks. Each generic task would be compared with similar competencies of the data bank and a training hours value accordingly assigned to the generic task. The analyst then estimates the training transfer commonality of each generic task with each relevant task. The impact of the training transfer effect of a generic task on each system task must be considered in a different manner than is the impact of a requirement (as a prerequisite) for a competency. The requirement for a competency is additional to the specific training required to accomplish a task, whereas the training transfer effect provides for the deletion of a portion of the task specific training. Since task specific training is a constant across two job components before and after merger (if training transfer is not being considered), the required task specific training does not need to be

considered in level 1 or level 2 definitions of the S/U measure. Thus, in the levels 1 and 2 concepts of the S/U measure, it was essential that anything contributing to training hours be entered only once for each job component. This contrasts with the logical need to subtract the training transfer effect from the task specific training for each task. Moreover the amount that should be subtracted from each task increases more tasks similar to the generic task are included in a cluster -- with the increment for adding another relevant task becoming less and less until an asymptote is reached. The formula for reflecting this desired relationship (of training transfer effect to the measure of required training hours utilized by the S/U measure) will be discussed further in the discussion section.

Functional Definition at Developmental Level 3. Developmental level 3 permits the consideration of: (1) learning decay rate and, (2) frequency with which each task will be performed. Training maintenance cost is more when learning decay rate is high and less as frequency of task performance increases. The primary developmental cost is in the addition of an estimated learning decay rate to each competency record in the data bank. The manner in which decay rate would be estimated will be covered in the discussion section. The frequency estimate will be provided by the analyst during the task data generation module.

In level 3 estimates of the S/U measure, the hours of training maintenance associated jointly with a task and a competency will be a function of the required frequency of training and the training time required of trainer and trainee to conduct a relevant on-the-job training session for the honing of that competency. The required frequency of training is in turn a function of learning decay rate and frequency with which competency is exercised across all tasks included in a job component. With sufficient performance frequency the required frequency of training goes to zero. As the learning decay rate is increased the amount of required performance frequency which will reduce the required frequency of training to zero goes up.

A General Description of the Algorithm for Optimizing the S/U Gain. The S/U measure will be initially computed for each task and placed in a task-by-task matrix. These individual tasks constitute the initial set of job components that will be considered for aggregation. This aggregation process includes the trial merger of a pair of job components yielding the highest S/U measure increment at each iteration and the testing (optionally) against the three constraint criteria relating to a minimum S/U measure increment, a maximum permissable technology complexity and the extent school and MOS boundaries are violated. If the trial merger passes all criterion tests stipulated by the analyst, the aggregation will be effected, the rows and columns representing the two components deleted from both the S/U measure and constraint matrices, and a new row and column added to represent the new (merged) job component. Thus the order of both matrices are reduced by one at the end of each iteration. The next iteration is proceeded by testing with respect to the stopping rules. That is, does any pair of job component candidates for further aggregation that meets all prescribed criteria remain.

The variables contributing to the S/U measure in each of the three developmental levels are summarized in Table 1. The computations required for each level 1 iteration to produce a S/U measure value falls into two steps, first the removal of all duplicate competencies, and secondly, the summing of

all initial training hours associated with each competency. The S/U measure obtained for two job components whose competency sets have been concatenated (aggregated with duplicates removed) is then subtracted from the sum of the S/U values computed separately for those two job components. When multiplied by (-1) this is the S/U gain increment that would be obtained from the candidate merger. These gain values are retained in a S/U increment matrix so as to preclude having to compute these gain values for more than one row per iteration.

Level 2 computations to obtain a S/U value include the same treatment of competencies as for level 1, except that training hours associated with a competency are weighted by an importance weight that is unique to a pairing of a task and a competency. Also, the training transfer effects associated with a task are subtracted from the weighted (by importance) sum of training hours attached to the competencies required by the task. The S/U gain is computed in the same manner as in level 1.

The level 3 version of the S/U measure uses the same computational process as levels 1 and 2 with the additional consideration of another variable (frequency of task performance) in conjunction with an altered procedure for arriving at training maintenance hours. The number of training hours required for training maintenance is computed as a function of: (1) training decay rate for the task and, (2) frequency of performance of the task, (3) the importance weight--and added to the S/U measure as it would be computed for level 2. The S/U gain is computed as in levels 1 and 2.

<u>The Overall Aggregation Process</u>. The overall algorithm for successively optimizing the S/U gain or increment includes rules for: (1) identifying eligible pairs, (2) computing the S/U gain, (3) selecting the best pair, (4) testing against additional criteria for evaluating the benefits from a proposed merger, (5) effecting the merger, and (6) determining whether the aggregation process is finished or another iteration should be commenced. This process is depicted in Figure 12.

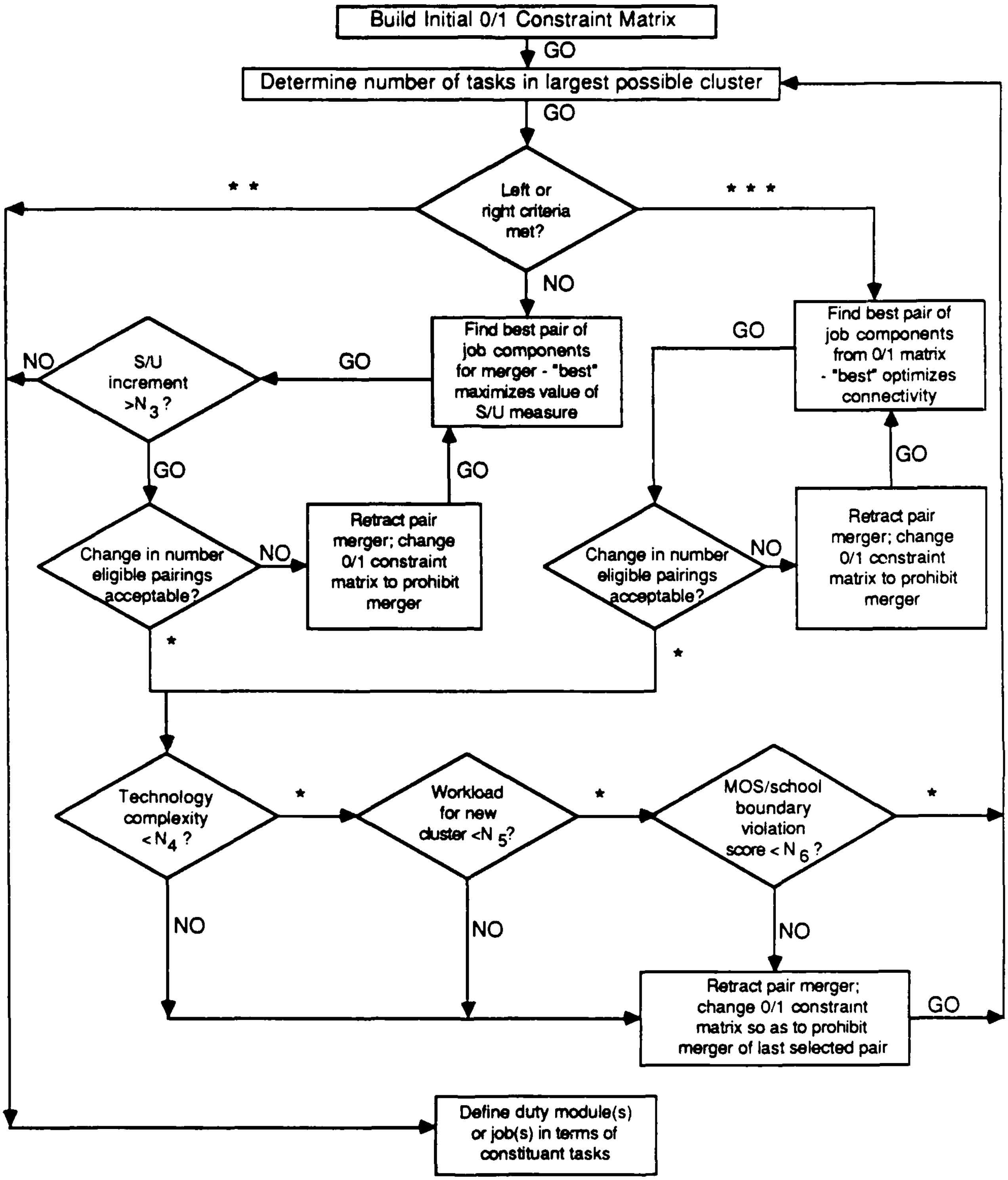
Several routes through the aggregation process are available depending on which options have been turned on by the analyst. One route, with selected options turned on and two options depicted as being available to the analyst, is shown in greater detail for the selected options as Figure 13.

PRODUCT DESIGN

<u>THE INFORMATION AND AIDS OF THE PRODUCT</u>

<u>Data Base (DB) Information</u>. Information content, apart from the provision of a process and analytic aids for the implementation of that process, is provided by four data bank files. The information provided in those data bank files can be directly accessed by the analyst and are available to be used, with the aid of the data bank shell, whether or not other parts of Product Five are also utilized.

The content and structure of these four data bank files are described above. These files are summarized in Table 2.



* Represents a pass through when option is turned off, or a yes when option is turned on.

* * Largest cluster (M) has number of tasks less than or equal to N_1 ($M \leq N_1$) on first iteration, on suceeding iterations branch if M is equal to order of matrix.

* * * Largest cluster (M) has number of tasks less than N_2 and greater than N_1 ($N_1 < M < N_2$).

FIGURE 12
Overall Aggregation Process

SCHEMATIC FOR AGGREGATION OF JOB COMPONENTS

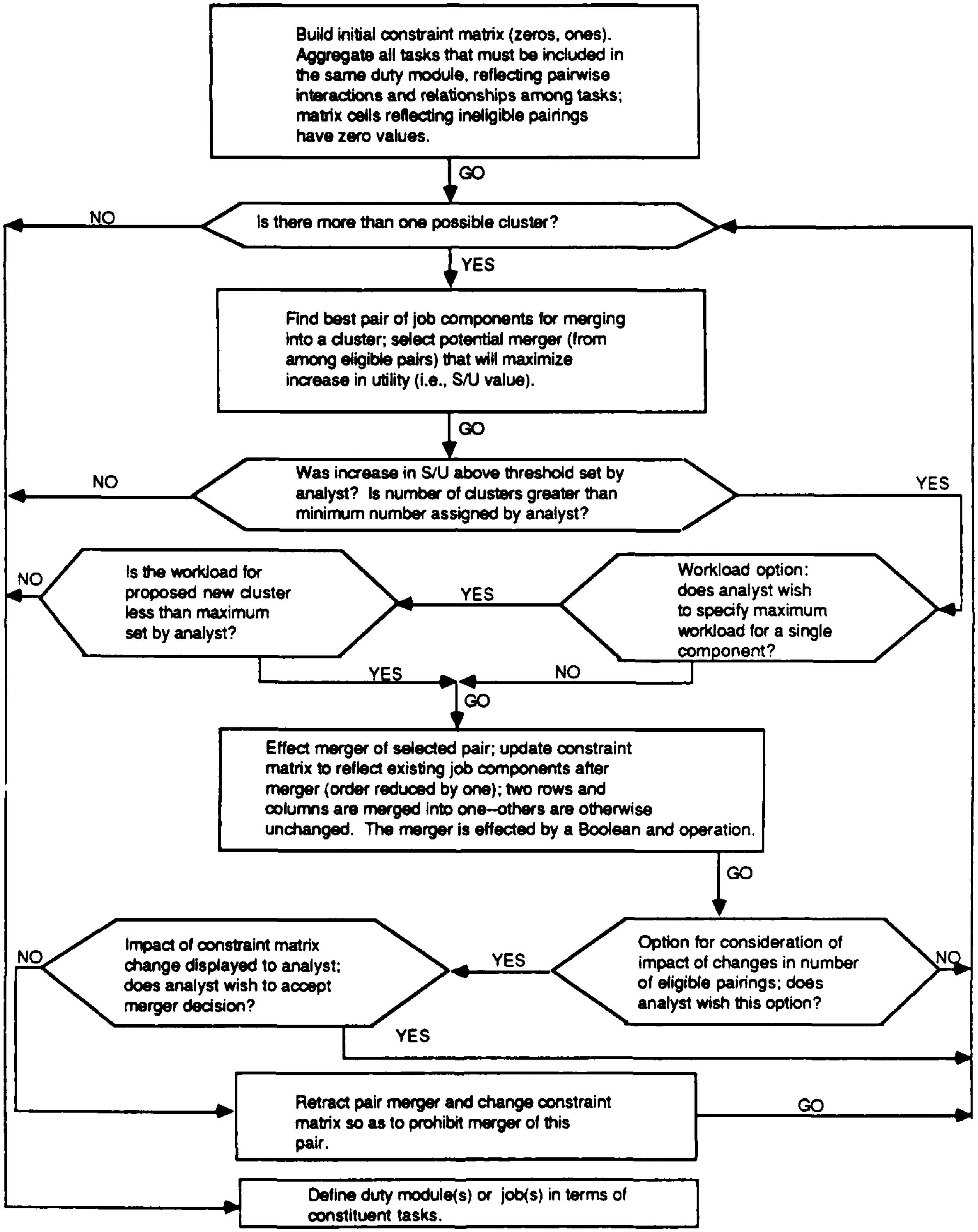


FIGURE 13
Aggregation of Lab Components

Table 2

The Four Data Bank Files

File Name	Content of Each Record	Descriptors
Competency File	At Developmental Levels 1 and 2	School Domain Category
	. Competency Short Title . Competency Long Title . Initial Required Training Hours . Short Description of Competency (Possibly in a Separate File Using Competency Short Title as the Descriptor)	. School and Course Title . System/Subsystem Category . Technology Category . Mission Category . MOS
	Additional for Developmental Level 3	
	. Required Frequency of Training Maintenance (Learning Decay Rate) for Each Competency	(A Descriptor Menu will be Provided user by shell--logical "and" or logical "or" can be used with multiple descriptors.)
Baseline Systems File	. Name of Systems/Subsystems Currently in Inventory . Associated MOS(s) . Associated School(s) . Descriptors Linked to Record	. Name of Candidate Baseline System . Otherwise same as for competency file; the analyst can obtain candidate descriptors for use in accessing competency file.
MOS and School Boundaries File	. Same as for Baseline Systems File	. Task data recorded on task data file will be used as descriptors. May include competencies, D/Cs, and descriptors used by analyst in accessing other DB files.

Decision Aids for the Use of DB Files. In addition to the shell, which permits the analyst to access each DB File, Product Five provides a decision aid to assist the analyst in accessing the Competency File, and the Baseline Systems File. These decision aids will assist the analyst in making any required judgments and will assist him in recording information extracted from the DB Files directly onto other working files, including the Task Data Working File that provides input for both the Aggregation Model and the School and MOS Boundaries Model. The School and MOS Boundary File is automatically accessed by the School and MOS Boundaries Model, using the Task Data Working File to obtain the descriptors, when the analyst selects the option of testing selected pairs against a specified minimum boundary violation score. The analyst can also directly access this latter file through the data bank shell.

Decision Aids for the Generation of Task Data. Several specialized decision aids for prompting and guiding analysts in the generation of task data will be provided. The decision aid for identifying and assigning scores to generic tasks will use a special working file on which to record candidates for further consideration and additional judgments prior to later transfer to the Task Data Working File. The decision aid for assisting the analyst in using the competency file will also write candidate competencies on a working file for his review before the later transfer of selected competencies to the Task Data Working File. Other decision aids with a greater scope, such as those discussed below, will also provide for recording the results on a working file--either the Task Data Working File or the Product 5 Output File.

Decision Aids for Taking an Analyst Through an Analytic Process. Other decision aids will guide and assist the analyst through an analytic process that includes information gathering, decision making, recording of partial results, reviewing of results and the recording of final results for output to either a working file or the Product Five Output File. One decision aid, incorporated in the Product executive, covers the total process and indicates when the analyst should make use of each of the other models and decision aids. The workload data generation decision aid covers a process that includes the use of the workload model. Similarly the Manpower and Personnel Requirements Decision Aid includes instructions for using the Manpower Requirements Model.

Product Five Models. The provision of relatively complex analyses using automatic input from the Task Data Working File, as well as the use of parameter and criterion (threshold) values provided by the analyst, is provided by the four models. Except for the Manpower and Personnel Requirements Model, which outputs to the Product Five Output File, all models automatically output to the Task Data Working File (duty modules and jobs are defined in an appendage to this file).

Of the four models, the computations performed are the most complex for the aggregation module. However, the identification and counting of the links between descriptors and school domains (as is accomplished in the School and MOS Boundary Model) could for some task sets confront an analyst, attempting to perform these steps manually with an even more difficult and confusing process. The other two models, the Workload Model and the Manpower Requirements Model, could conceivably be programmed on a programmable hand calculator possessing a moderately large memory, provided the analyst was experienced and competent or guided by a decision aid of the type provided by

Product Five. It makes more sense, of course, to place these two models within the same overall software shell as contains the other two Product Five models.

<u>The Information Needs of the Analyst</u>. System implementations to be processed through Product 5 will come to the analyst with varying amounts of information regarding the design features and operational doctrine of the system. The information will not only come with varying degrees of completeness but will arrive in varying formats and with information gaps occurring for different parts of the system. The analyst must not only perform as a transducer to convert the available information into the content and format required by Product Five, but must creatively gather additional information that did not arrive in the packet sent to the analyst from higher headquarters (or from a sponsor). The Product Five decision aids can prompt the analyst as to what is needed but the analyst remains the transducer.

Similarly, the information on baseline systems to be utilized in workload data generation must be obtained by the analyst. It would not be economical to build a data base containing such perishable information over such an extensive domain. It is most practicable for the analyst to obtain this information as it is needed, just as is true of MIST.

In general, the information needed by the analyst, but not provided by one of the four data bases of Product Five, is information that the analyst would also have to obtain in much the same way if he were using MIST or other available methodologies.

<u>Information Provided by Product Five</u>. The analyst may access the data base files to obtain estimates of training costs and/or technological complexity for tasks relating to proposed design changes, or for tasks judged to be high driver tasks based on information from other products or from other prior analyses. Other intermediate outputs, such as the technical complexity of jobs containing specific tasks or the number of viable duty positions required, may be utilized to answer specific questions posed from higher headquarters or sponsors.

In addition to the final output file provided by Product Five, the analyst may conduct "what-if" analyses in which the estimated impact of design changes in the developmental system being analyzed is assessed. Similarly additional iterations could be executed with changed Product Five aggregation criteria and constraints if Product Six results indicate unsatisfactory qualitative demands.

The final output file will be provided in two formats, one in the precise format that Product Six requires for an input file, and secondly in a format that provides maximum readability and understanding for the use of the analyst. The analyst will review this second file before determining that the first file is ready to be provided as Product Six input.

The information output from Product Five will include jobs and duty modules in terms of the constituent tasks; the number of each job required for specified maneuver units and and/or support units; and the number of each job required for the total Army to provide for the fielding of a specified number

of systems. Also, optionally, the recommended MOS School domain, technological complexity, and competency requirements of each job can be provided.

TASK AND DATA GENERATION METHODOLOGY

Task Data Requirement. One input requirement to the Product Five process will be human operator and maintainer tasks. It is our assumption that what a person does is the primary determinant of the characteristics that person must possess to do it. The determination of these tasks may be a difficult problem, since at the time Product Five is to function all that may exist describing the soldier, hardware and software system are drawings on blueprints or CRTs. One such source of task information will be the Human Engineering Design Approach Documents for operators and maintainers (HEDAD-O and HEDAD-M). These documents describe in considerable detail (drawings, time estimates, and textual descriptions) the human tasks to be performed in operating and maintaining the proposed system. Recent major material RFPs (e.g, LHX, T800, and AFV) have required that the HEDAD-O and HEDAD-M documentation be provided very early in the design process, (i.e. before down-select or prototype development). Because of the importance now being assigned to MANPRINT concerns, it is now likely that most weapon system designs will have HEDAD information produced early in their development process. Given their high level of detail, these documents will be excellent sources of task information for Product Five.

While the HEDAD-O and HEDAD-M are excellent sources of task descriptions and information, we recognize that Product Five may from time to time be called upon to evaluate an interface design for which the HEDAD documents have yet to be completed. To provide for these occasions and to furnish backup material for the HEDAD-O and HEDAD-M, we will develop and submit as an adjunct to the Product Five evaluation mechanism a design interface-to-human task (operator and maintainer) generating mechanism. The advantage of this mechanism, as an input to the evaluation process, is that it will always be available.

Other sources of task data are contained as elements within the Early Comparability Analysis (ECA) portions of the HARDMAN and MIST procedures. These procedures tend to group tasks into MOS rather than jobs or duty positions so their output is at a higher level of aggregation.

Task Generation Capability. Task Analysis is a time-oriented description of personnel equipment and software interactions brought about by an operator, controller or maintainer in accomplishing a unit of work with a system or item of equipment. It shows the sequential and simultaneous manual and intellectual activities of personnel operating, maintaining or controlling equipment, rather than a sequential operation of the equipment.

The analysis of tasks will provide one of the bases for evaluating design decisions; e.g., determinating, to the extent practicable, before hardware fabrication, whether system performance requirements can be met by combination of anticipated equipment, software, and personnel, and assuring that human performance requirements do not exceed human capabilities. These analyses are also used as basic information for developing preliminary manning levels; equipment procedures; skill, training and communication requirements; and Logistic Support Analysis inputs, as applicable. The gross tasks identified during human engineering analysis, which are related to end items of equipment

to be operated or maintained by personnel and which require critical human performance, reflect possible unsafe practices or are subject to promising improvements in operating efficiency, are being further analyzed.

Critical performance is that human performance which, if not accomplished in accordance with system requirements, will most likely have adverse effects on cost, system reliability, efficiency, effectiveness, or safety. Critical performance is usually part of a "single" line of flow in the operation or maintenance cycle of the system. An example of a "single" flow involving human performance is the transmission of a message which must be passed for operations or maintenance cycles to commence or to continue, such as an order to prepare a missile for launching. If this order is not passed, or if it is garbled, the entire missile operation cycle may cease to function as required. Human performance will also be considered critical whenever equipment design approaches limitations (e.g., human performance functions and tasks are too demanding, information presented to personnel is inadequate to meet human performance requirements, appropriate information displayed is not perceived, or controls provided cannot be effectively operated) and thereby significantly contributes to the occurrence of one or more of the following conditions but not necessarily limited thereto:

(a) Jeopardized performance of an authorized mission.

(b) Degradation of the circular error probability (CEP) to an unacceptable level.

(c) Delay of a mission beyond acceptable time limits; e.g., human time to react will not meet required system reaction time.

(d) Improper operation resulting in a system "no-go," inadvertent weapons firing, or failure to achieve operational readiness alert.

(e) The exceeding of predicted times for maintenance personnel and maintenance ground equipment (MGE) to complete maintenance tasks. As a rule, performance times will be considered critical if the total maintenance response time significantly exceeds maintenance analysis estimates, and affects MGE quantitative requirements.

(f) Degradation of system equipment below reliability requirements; i.e., mean time between failures (MTBF) is reduced.

(g) The damaging of system equipment, resulting either in a return to a maintenance facility for major repair, or in unacceptable costs, spare requirements, or system downtime.

(h) A serious compromise of weapon system security.

(i) Injury or illness to personnel.

<u>Analysis of Critical Tasks.</u> Further analysis of critical tasks will identify the: (1) information required by operator and maintainer, including cues for task initiation; (2) information available to operator and maintainer; (3) evaluation process; (4) decision reached after evaluation; (5) action taken; (6) body movements required by action taken; (7) workspace

envelope required by action taken; (8) workspace available; (9) location and condition of the work environment; (10) frequency and tolerances of action; (11) time base; (12) feedback informing operator/maintainer of the adequacy of action; (13) tools and equipment required; (14) number of personnel required, their specialty and experience; (15) job aids or references required; (16) communications required, including type of communication; (17) special hazards involved; (18) operator interaction where more than one crew member is involved; (19) operational limits of personnel (performance); and (20) operational limits of machine and software. The analysis will be performed for all affected missions and phases including degraded modes of operation.

Task Analysis Hierarchy. The following hierarchy is used to inventory or analyze tasks, with levels (a) and (b) stated by the procuring activity and the remaining levels dependent on the current phase of system development and purpose (e.g., gross analysis of tasks, analysis of critical tasks) for which the analysis is being conducted (Zavala, 1980).

(a) Mission - What the system is supposed to accomplish, e.g., combat reconnaissance.

(b) Scenario and Conditions - Categories of factors or constraint under which the system will be expected to operate and be maintained, e.g., day and night, all weather, all terrain operation.

(c) Function - A broad category of activity performed by a system, e.g., transportation.

(d) Job - The combination of all human performance required for operation and maintenance of one personnel position in a system, e.g., driver.

(e) Duty - A set of operationally-related tasks within a given job, e.g., driving, weapon servicing, communicating, target detection, self protection, operator maintenance.

(f) Task - A composite of related activities (perceptions, decisions, and responses) performed for an immediate purpose, written in operator and maintainer language.

(g) Sub-task - Activities (perceptions, decisions and responses) which fulfill a portion of the immediate purpose within a task.

(h) Task Element - The smallest logically and reasonably definable unit of behavior required in completing a task or sub-task.

Task Analyses Generation. Product Five is conceptualized to have the capability to transfer or create task analysis information for storage in its data management system in the task hierarchy discussed above. The transfer function of the task analysis generator is provided to convert available task analysis data in model forms, such as HOS, MICROSAINT, and Modified Petri Net (MPN) System. This conversion is accomplished by ACSII processing. We have already written code for this conversion for MICROSAINT. The Army Human Engineering Laboratory is developing Perceptronics MPN for MANPRINT evaluation. The major point to be made is that Product Five will be usable by Army

MANPRINT personnel at different locations without restricting the task analysis technique, workload model, or user's preference.

The second function of the task generator is to create the information. This creation of task analysis information is accomplished by the user interacting with the user interface system and adaptive protocols. The tabular format of the task analysis contains the following information: (1) Function Sequence - identifies the functional block for this task sequence; (2) Task and Sub-task Numbers - identifies that specific task with the given sequence; (3) Task Element Descriptions - describes the specific task to be done; (4) Estimated Task Time; (5) Accumulated Task Time; (6) Task Critically - relative importance of task to the completion of the mission and scenario and conditions; (7) Operator Control and Display, or Maintainer Equipment, Description; (8) Operator Panel Location, or Maintainer Equipment, Location (zone) (e.g., identifies panel where switch or control is located); and (9) Task Element Sensory and Motor Load, i.e., visual, right hand, left hand, communications, or feet; and (10) Task element information processing, cognitive, or decision load. These are required data to establish the task requirements related to each mission and scenario and conditions.

Network Methodology. Prior to generating the task information above, the user has the ability built in the Product Five system to create task (block) networks. This capability is critical since the sequential or parallel relationship to other tasks is important data for this aid. A network consists of one or more sets of connected task or sub-task blocks. This task level of network flow is adequate for the experienced modeler upon which to build the task input statement information. Each block describes a task or sub-task in terms of stimulus- organism-response (S-O-R) data elements. All (S-O-R) data elements must be accounted for, explicitly or implicitly, in the network. A block contains any or all of the following personnel functions.

(1) Time delay elements.

(2) Task 1 element (visual or auditory) - STIMULUS.

(3) Information processing element - ORGANISM.

(4) Task 2 element (right-hand, left-hand, feet, or communication)- RESPONSE.

In addition to the above, a task block also includes the following elements:

(1) Human probability decision points following the task 1, information processing, and task 2 elements.

(2) Equipment probability decision points following the task 1 and task 2 element.

(3) A task recycle probability decision point.

(4) Predecessor and Successor task blocks corresponding to the points where a block may be entered or exited.

(5) Attribute values (e.g., means, standard deviations).

WORKLOAD GENERATOR

Perceptronics MPN Workload Model. Task analysis can be performed for many different purposes (e.g., development of job aids, functional allocation, performance and workload prediction, training, training material and training aids development, and man-machine interface design). Typically, different task analytic approaches have been brought to bear, depending upon the specific purpose of task analysis. The MPN model-based approach is unique because it addresses each of the purposes for task analysis required by advanced weapon system design. For example, using MPN analysis, strong guidelines can be derived for function allocation. A good approximate analysis for sound performance and workload comparisons of alternative function allocation options can also be performed. Man-machine interface load can also be studied within the MPN framework geared to describing tasks at the man-machine interaction level. Finally, the MPN model can also be used to simulate expert performance and behavior in intelligent tutoring systems (ITS) for developing Intelligent Training Delivery systems. In the following paragraphs, the various applications of the MPN model for the workload prediction and assessment will be described in terms of inputs, outputs, processes and the specific knowledge that can be embodied depending upon the specific requirements of the application.

The MPN model is a network of human information processing tasks or activities (perceptual, cognitive, and psychomotor) and events (internal or external to the man-machine system) in which the possible precedence of variables among activities and events can be parsimoniously represented. In addition, the network model is an active, executable model capable of describing and predicting human performance and workload under different environmental, task, and function-allocation conditions. The active property of the MPN framework arises from the fact that it is a token-marked graph. As the net executes, a token propagates in response to external or internal events. Token propagation is defined by token propagation rules. Token propagation patterns provide a well-defined trace or audit-trail to which explanations can be linked in a clear fashion.

Uses of the MPN Models. The MPN analysis will be used in six different ways within the workload analysis: (1) as a means for determining all possible task concurrencies, (2) as an initial guide to function allocation, (3) as a means to verify the reasonableness of data generated from manned, part mission part-task simulation, (4) to evaluate alternative automation concepts and man machine interfaces, (5) as a "driver" of selected nodes in mission characteristics models, and (6) to provide a rationale for human performance and workload prediction function allocation. Each of these uses is described in the following paragraphs.

(1) MPN-Based Task Concurrency Analysis. One of the problems in task analysis is determining what tasks are frequently performed simultaneously. This has obvious implications for identifying high-workload situations and for suggesting possible options for functional allocation. To this end, the MPN-model will be executed in a Monte Carlo mode to expose all the possible task concurrencies. An important by-product of concurrency analysis is in elicitation of workload for both individual and concurrent tasks. Experience shows

that tasks that are structually dependent in terms of skills or that share human resources do not produce additive workload. This appears to be because the human operator tends to sacrifice performance on one task to perfrom all tasks acceptably. Eliciting the workload for all such concurrent tasks gives a far more accurate picture when the MPN model is executed for workload and performance predictions (Madni, 1985). It has also been shown that even experienced pilots cannot supply all the task concurrencies that can occur in a typical mission scenario. Consequenctly, the use of MPN to this end is a major contribution to the task process.

(2) MPN Analysis for Function Allocation. In this analysis, the tasks are encoded within Modified Petri Nets at a level of abstraction that allows identification of whether the tasks are predominantly perceptual, cognitive, or psychomotor in nature. The input data at this point is the event stream from an event sequencer and times elicited from experts. The MPN models are executed in Monte Carlo mode and workload and performance envelopes are computed for the total task. Following this, the subnets associated with each concurrent path are executed in a "What-if" mode directed at extraction of the fractional contribution of each concurrent path (activity sequence) to the overall task. This process, which determines the partial contributions of each activity sequence with respect to the overall task, is capable of providing strong guidelines for candidate function-allocation schemes. The use of this information in conjunction with the suitability of the machine to perform these tasks provides a sound basis for developing and testing alternative function allocation options.

(3) MPN as a Verification Tool for Part-Task Simulations. In this capacity, the MPN model is driven by the actual scenario events recorded in the manned, part-task simulation. The MPN model is executed and the performance and workload results are compared against protocol analysis. On the one hand, this process verifies the results of the part-task simulation and, on the other, suggests guidelines for expanding the MPN model to the lower levels of abstraction required for candidate automation concept evaluation and comparison of man- machine interface options.

(4) MPN Models for Evaluation of Automation Concepts and Man-Machine Interfaces. In this capacity, the MPN models are developed in detail at multiple levels of abstraction to evaluate the performance and workload resulting from alternative automation concepts and man-machine interfaces. At the lowest level in the MPN hierarchy, the activities are the specific actions of the human via a specific control input or in response to a specific display generated by the automation.

(5) MPN-Based for Mission Characterization Model. The MPN model in this capacity can be used to provide selected performance statistics for the mission characterization model, which is a network of different types of nodes (equipment, humans, etc.) with their associated probabilities of contributions to overall mission success.

Performance statistics can be generated by the MPN analysis to investigate the impact of any selected note on mission success.

The MPN-based analysis approach provides a consistent framework for:

(a) Identifying the possible task concurrencies in the course of a mission scenario.

(b) Guiding the development of function allocation options.

(c) Evaluating the impact of different function allocation options on operator performance and workload.

(d) Evaluating the efficiency of alternative automation concepts and human-machine interfaces.

(e) Predicting overall workload and performance associated with critical mission segments.

(f) Providing performance statistics for mission characterization model.

(6) Rationale for MPN-Based Human Performance and Workload Prediction for Function Allocation. In order to predict human performance and workload, specific scenarios must be addressed. Given a scenario, the interactions of the human and machine need to be captured in both a descriptive and prescriptive sense. The former is necessary so that all the relevant dimensions can be laid out for consideration by the human or automated tools attempting to predict the behavior of the human working with the machine. The latter is necessary because it is difficult for the human designer to predict performance in an uncertain environment given the different problem dimensions.

This leads to the need for a prescriptive tool. From the descriptive and prescriptive requirements stem three key criteria for adopting a human performance and workload prediction tool. First, it is necessary for the approach to be model-based if the subjectivity in these assessments is to be reduced. At the heart of the model-based approach is the representation of all task-related knowledge. Second, if the tool is expected to prescribe or predict, it can only do so if it is in the form of an executable piece of software. In other words, the representation has to be dynamic, not static. Third, if the tool is expected to be used, it should be verifiable against simulator data, laboratory experiments, and flight tests. This calls for a model that is "glass-box" rather than "black box" in nature.

Of the various disciplines that have attempted to tackle this problem, the most prominent have been cognitive psychology and decision analysis, operations research and control theory, and artificial intelligence and expert systems. Cognitive psychology provides principles for human behavior in decision-making contexts. Belief that humans confuse objectives and options, fixate upon the most recent piece of information inadvertently impose

constraints on the problem that sometimes pre-empts creative option generation, and tend to be poor aggregators of information, is the legacy of cognitive and behavioral psychology. However, there is no formal or unifying representation within cognitive psychology that satisfies the requirements of rich description, prescription (via executable software), and verifiability. Therefore, while cognitive psychology provides vital insights, it does not provide a modeling framework for prescription analysis.

Decision analysis offers a normative framework for problem-structuring, option evaluation, and option selection. Specifically, Multi-Attribute Utility (MAU) models and decision trees are two useful modeling frameworks. MAU models are highly-suitable for characterizing mission goals and tradeoffs among the objectives that characterizes the attainment of the goal. However, they are not a static framework capable of capturing explicit events, task concurrencies and uncertainties associated with air combat tasks. Decision trees provide a convenient means for structuring the problem and for function allocation and automation. Operations research techniques, such as linear programming, have seen some use in decision aids for resource allocation. However, linear programming techniques solve static optimization problems that do not characterize air combat tasks.

Perhaps the most significant contribution of operations research is the GERT and Q-GERT type network models that produced analysis software such as SAINT and SLAM and their micro-based versions. These techniques have been used by some of the major airframe manufacturers for task and workload analysis. However, these techniques typically have one major shortcoming. They lack explicit handling of the cognitive component in task performance. This is not surprising because, at the time these models were developed, automation and AI and expert systems technology were not far enough along to make cognitive modeling a viable goal. In addition, since they operate primarily through the SAINT- and SLAM-type models they tend to be somewhat tedious and provide a batch rather than a truly interactive process. Finally, the user interface needs significant improvement in these software models.

A key contribution of control theory is optimal control models of the human operator. While these models are highly suitable for tracking tasks and strike sequencing problems, they are incapable of handling the cognitive contribution to the problem except in an input-output sense which leads to the "black-box" representation of the problem. The lack of transparency and correspondence with physical reality make these classes of models highly unsuitable as an analytic tool for making task performance and workload assessments. This brings us to AI and the attendant knowledge representation techniques associated with expert systems development. These techniques include production rules, frames, propositional and predicate calculus, scripts, associative and semantic nets, directed graphs, AND/OR graphs and network models. Most of these techniques capture some aspect of the problem such as relationships, conditions, causality, precedence, or events. However, when requirements of parsimony, executability, and representation power are applied, none of these methods independently achieve these ambitious goals. For example, production rules with procedural attachments can capture all aspects of behavior (i.e., both the what and how) but typically tend to grow combinatorially, thereby violating the requirement of parsimony. In addition, as the size of the rule set increases, ad hoc methods have to be brought to bear to limit the sampling of just the relevant rule set in the face of

changing environmental conditions. Similar problems exist with some of the other techniques. The modeling approach that satisfies the requirements of representation power, executability, and verifiability along with parisimony and tractability are Modified Petri Nets. These models developed by Madni et al., (1984) build on the original work of Petri in 1961. These models possess the characteristics summarized in Table 3.

Table 3. Modified Petri Net (MPN) Capabilities For Operator Combat Task Analysis

Representation Power
- Decisions
- Events and Associated Ucertainties
- Concurrent and Asynchronous Tasks and Processes
- Priorities
- Activities (Perceptual, Cognitive, Motor)
- Time tied to Occurrence of Events
- Variable Precedence Among Events and Activities
- Multiple Levels of Abstraction

Prescriptive Power
- "Executable" Network Software
- Workload Envelopes and Comparisons
- Performance Envelopes

Verifiability
- Against Manned Simulations
- Laboratory Experiments
- Flight

Explanation Power
- Audit Trail Maintained via Token Propagation
- Patterns Explanations Specifically Tied to Tokens

JOB COMPONENT AGGREGATION: MEASURES AND ALGORITHMS

The clustering algorithms that operate on either 0/1 or S/U matrices are straight forward, neither providing appreciable developmental or acceptability risk, nor offering to dramatically extend the state of the art. It is the content of the 0/1 and S/U matrices that pose the greater problems and opportunities to exercise creativity. It is the proposed and alternative approaches for arriving at values for the cells of those matrices and the values for the technological complexity and boundary violation variables for each job component that will be discussed in this section. However, since the nature of the competency variable depends so heavily on the design and use of the data bank, all measurement issues relating to competencies will be discussed later under the data bank topic.

The Methodological Confidence Continuum--From the Fully Determined to the Relatively Unknown. The confidence placed in the overall soundness of the methodology associated with the variables used in the aggregation process vary with respect to several dimensions. These dimensions include the following:

(1) Quality of metric.

(2) Certainty that values for the variable can be validly and reliably estimated.

(3) Face valid relevance of the variable to the decision it is influencing (relevance).

(4) Closeness of the variable to the ultimate utility function (validity against the ultimate criterion).

The Rank Order is Important. Such variables as technological complexity and task performance frequency can be ranked on each of the above four dimensions. These rank orders are provided in Figure 14 for a number of variables using A as best (deserves the most confidence), B as upper intermediate, C as lower intermediate and D for those tied at the bottom of the rank order. Since these letters represent rank order, rather than an evaluation, at least one variable will have a D on each dimension. The dimensions are represented in Figure 14 by the underlined words in the above descriptions. The top variable in Figure 14 has the highest overall rank order just as the bottom variable has the lowest overall rank order on the confidence continuum.

Consequences for development of a low rank order displayed in Figure 14 is not in itself an argument for the deletion of a variable from Product Five. Instead, such a ranking indicates the need for special attention to such a variable during the developmental process. The means of defining and placing values on the lower ranking variables will be discussed at greater length than those variables that ranked at the top of Figure 14.

Alternative Approaches Considered and Rejected. Determination of task similarity in terms of system and sub-system and technology simularities was addressed. The need for a clustering process, as in the clustering of tasks into jobs, immediately brings to mind the principle of placing like things together. To do this a similarity measure is required. If a relevant similarity measure can be credibly identified; one that also passes muster with respect to its metric quality, reliability, validity with respect to a utility function, and relevance to Army doctrine and MANPRINT objectives--then traditional algorithms, for maximizing similarity within clusters and minimizing similarity across clusters, can be utilized.

One similarity measure considered for use was the degree of commonality with respect to systems and sub-systems and relevant technology for maintenance tasks, and with respect to missions, functions, and activities for operator tasks. Such a measure received a very poor evaluation for its metric quality and its lack of relationship to an important underlying utility function. Such a similarity measure does not assure that a soldier who can perform well on a given task can be expected to perform well on "similar" tasks. Nor can one be reasonably certain that training time is reduced proportionately to the increase of task homogeneity within a cluster. The metric appeared to yield an ordinal scale rather than the interval scale needed to compare increments in a measure of similarity across clusters and iterations. For those reasons a S/U measure more clearly related to a

RANK ORDER* OF AGGREGATION VARIABLES
FOR FOUR DIMENSIONS AFFECTING CONFIDENCE

Overall Rank Order	Aggregation Variables	Dimensions Affecting Confidence (see text for definitions)			
		Metric	Reliability	Validity	Relevance
1	Time to Perform Task	A	C	A	A
2	Frequency of Task Performance	A	C	A	A
3	Enabling Skills Training Time	B	A	C	B
4	Task Level Skills Training Time	B	B	C	B
5	Generic Task Skills Training Time	B	B	C	C
6	Importance Weighting	C	C	C	A
7	Technology Complexity	D	C	B	A
8	Learning Decay Rate	C	D	B	B
9	Training Transfer Rate	C	D	C	C
10	MOS/School Boundary Violations	D	A	D	D

*"A" indicates that variable is tied at the high end of the confidence continuum, D represents the low end.

FIGURE 14. Rank Order of Aggregation Variables

desirable utility function was sought, eventually leading to the consideration of the S/U measure and algorithm proposed in this report.

The use of a Simulation Model was also addressed. A simulation model to estimate system performance with different numbers of operators and maintainers could conceivably be used in a series of "what if" experiments, to obtain the number of soldiers, and a division of labor within the system that would identify jobs--both being accomplished with the degree of specificity permitted by the parameters of the simulation model. For example, the ARI MANMODEL would permit the determination of system performance with various manning configurations in TOS (the division and corp level command and control system proposed for development about ten years ago). The Navy "ships" model would have provided similar data for both operator and maintenance tasks on a specified type of destroyer.

The major problem with this approach lies in the virtual impossibility of creating a general simulation model that can provide system performance estimates for alternative manning configurations across widely different systems. The cost of providing different MANMODEL type simulation models for such systems as FAADS, the Bradley, a self propelled howitzer, a light machine gun, etc., for over a dozen widely different systems would be prohibitive. The ARI SIMPO program provides some examples of potential pitfalls associated with the development of overly general models. This program had the objective of creating a "General Matrix Generator" model that would avoid the necessity of programming custom designed network flow models to solve each problem posed by a sponsor. As other organizations have also discovered in other situations, it turned out to be just as fast to write a new program to implement a custom designed model as compared to the effort required to manipulate the parameters on the "general" model--plus, the custom designed models were typically 20 times faster than the general model. It should be noted that these problems were occurring with relatively similar situations to be modeled, as compared to the diversity in mission, function and technologies that will occur among the new systems that Product Five will be applied to over a 3 year time span.

TECHNOLOGICAL COMPLEXITY

Investigators conducting MANPRINT analyses for industry have noted that the Army has several criteria for determining Aptitude Area "cut scores" for Army School Applicants--in addition to the perceived cognitive loading of the tasks to be performed. One of these criteria appears to be the complexity and technical sophistication of the systems with which the incumbents work. This criterion is the variable that is referred to as technological complexity in this concept paper.

It was noted that the S/U measure proposed for use in Product Five is closely related to technological complexity. When more enabling skills and higher level task skills are required to accomplish a job component, upon the merger of two tasks to form this component, the increased demand being made on the incumbent appears to be similar to the demands that increasing the technological complexity of the system would make. However, it is believed that a maximum S/U measure score and a maximum score reflecting the technological complexity of the system(s) should be separately considered by

the analyst in determining the acceptability of a particular cluster of tasks (as a duty module or job). Most job component mergers will increase both the S/U measure value and the technological complexity score when compared to either of the two components considered separately. Since the "best" pair of candidate components is selected on the basis of maximizing the S/U gain (the difference between the sum of the two constituant components, S/U measure values and the S/U measure value for the merged component--this difference then multiplied by (-1)), the steadily increasing S/U measure and/or the steadily increasing technological complexity score could reach an unacceptable level before the workload threshold or minimum gain increment is reached. Thus, it is essential to provide the analyst the option of setting threshold values for either or both variables (S/U measure value and/or technological complexity score) that will be used to test the acceptability of each merger selected as "best" by the aggregation algorithm.

Measurement of Technological Complexity. The assignment of a technological complexity score will be accomplished in two steps: (1) the identification and selection of technological dimensions and categories considered to be relevant to the set of tasks to be aggregated, and (2) the assignment of complexity scores to each task for each relevant dimension and category. A decision aid will provide prompts and aiding for both processes. A technology data bank file will be referenced by the decision aid during the first step and the selected dimensions and categories placed on a working file that will in turn be utilized in step 2 for the recording of complexity scores assigned by the analyst. This working file will then be used during the aggregation process for each iteration for which the analyst chooses to use the technological complexity option.

The technological dimensions and categories found in the data bank file may sometimes be adequate for the Product Five analysis of a set of tasks without the use of additional custom made dimensions and categories (D/C). A useful D/C must be present in some tasks and not in others that are eligible for aggregation. Any D/C that cuts across all the tasks under consideration will obviously contribute nothing to the analysis. Thus, the analyst will frequently wish to add additional D/Cs that represent subcategories of technology within some of the broader D/Cs found in the data bank file. Each such custom made D/C should have sufficient independence of all others selected to permit the assumption that an average score (e.g., 10) over any set of N D/Cs represents more technological complexity than would that same average score over any set of N-1 D/Cs.

After selection of an appropriate set of D/Cs, the analyst will review and confirm the relative complexity of D/Cs as recorded in the data bank file. For the new D/Cs the analyst will assign a comparable D/C complexity score (independent of the complexity level at which that D/C is required in each separate task).

A decision aid will provide prompting and decision aiding to the analyst for the assignment of complexity scores to each combination of task and relevant D/C. This process will take into consideration factors that also contributed to the D/C complexity scores including the following: (1) the general maturity of the science or technology as applied to the type of system at issue: (2) the extent the technology is commonly: (a) not even introduced, (b) introduced, or (c) well covered--at various educational levels ranging

from eighth grade general science, through High School science courses in 1 year technology programs, to college level science courses. In addition, more task specific factors such as the depth of the D/C required to perform each task and the degree to which the incumbent will be shielded from needing to understand the technology (e.g. by decision aids and/or other job aids).

Use of Technological Complexity in the Aggregation Process. The technological complexity score for a cluster of tasks (a job component, duty module, or job) is obtained by first concatenating the sets of D/C's attached to each of the constituant tasks. the complexity scores attached to each D/C in the resultant set are summed. This sum is the technological complexity score for the task cluster.

The computation of a technological complexity score for a job component, after the analyst has assigned his task-D/C technology scores, is accomplished in a manner that is completely parallel to the computation of a S/U measure for a job component. As with a S/U measure, the technological complexity score for a merged composite is always equal to or greater than the sum of the technological complexity scores of the constituant composites.

Since the "best" pair of candidate components is the pair with the largest S/U gain, and the largest gain implies (in general) the smallest increase in S/U value resulting from a trial merger, the trend is for successively larger increments in the S/U value (before computing the difference) through successive iterations. A similar increase in the magnitude of technological complexity score increments can be expected in successive iterations.

The Role of Technological Complexity in the Aggregation Process. The analyst has the option of setting separate threshold values for which neither S/U measures nor technological complexity scores may exceed during a clustering process. Thus, technological complexity can be used as a criterion score in much the same way as can be a maximum S/U measure value, the maximum workload total hours, and a maximum School and MOS Boundary Violation score. This is in contrast to the use of the S/U gain score as an objective function for determining "best" pairs for trial merger at each iteration of the aggregation process.

The metric for the technological complexity variable is considerably inferior to the metric of the S/U measure. With care, a good ordinal scale can be created so that the sum of the D/C scores can provide a basis for saying that composites having a higher value for one sum of scores has a greater degree of technological complexity than a composite yielding a smaller sum of such scores. However a difference score, of the type used to compute the S/U gain score, could not be trusted to be comparable at the high and low ends of the scale. Thus, the metric for the technological complexity score does not meet the desired standard for an objective function scale. Neither does this variable have a sufficient face valid relationship to an underlying utility function to justify its use as an objective function, although its relationship to one facet of a credible utility function (qualitative manpower requirements) is adequate to justify its use as a threshold criterion variable.

Opportunities for Job Engineering. When jobs identified by Product Five appear to be either uniformly too high or uneven with respect to technological complexity, the analyst may wish to lower the criterion threshold value previously assigned to the technological complexity variable, while adjusting other parameter values (e.g. for the minimum S/U gain score) to force more consideration of technological complexity in the clustering process. Most of the traditional goals of job engineering are obtainable through the appropriate manipulation of threshold values for criterion variables and/or the careful relaxation of the constraints that produce the 0/1 matrix.

POSSIBLE EXPANSION CAPABILITIES

Funding availability for Product Five is likely to permit level 1 development only. Consideration of training transfer effects, teaming decoy rate, and importance weighting would be considered for developmental levels 2 or 3 (see Table 1 above). The following discussion on each of these expansion capabilities is only for information and general consideration at this point.

TRAINING TRANSFER

The process of tabulating the reduction of training costs that can be accrued as a result of merging two job components should consider all training requirements that are common to two or more of the tasks eligible for merger. By this reasoning, the training needed to acquire all types of skills or knowledges not unique to a single task should be candidates for inclusion as components of a S/U measure.

The skills and knowledge not unique to a task fall into categories with radically different implication for the computational mechanics involved in assuring their appropriate contribution to the S/U measure. Those skills and knowledges, both elementary and advanced, that are, in their entirety, prerequisite for the learning of more specific task skills, are easily dealt with as "competencies" with rules for concatenating sets of competencies across components as they are merged. However other tasks with sufficient similarity to other tasks as to make it intuitively obvious that the capability to perform one such task reduces on-the-job training requirements for the others requires a different computational treatment. The skills in this category provide the basis for some tasks affecting others through "training transfer effect". It is intuitively credible that the commonality of such skills provides a high probability that an incumbent who can do well on one task will also be able to perform well on other tasks having a high commonality of such skills.

The benefits accrued from training transfer effects (expressed as training hours) when two job components are merged have an effect which is of the same sign as the S/U value different score that, when multiplied by (-1), provides the S/U gain score. Thus, both the S/U gain and the D/C gain are obtained by subtracting the score associated with the concatenated categories (competencies in the one case and C/Ds in the other) of the merged job component from the sum of the training hours associated with the categories required by the two constituant job components. The negative sign of both these effects are conceptually correct since they are, in theory, being subtracted from a large total number of training hours (a total that is not needed for the aggregation algorithms, and is unknown). The two effects (the

S/U gain score obtained from considering competencies and the D/C gain score) will be added together and multiplied by (-1) to form the S/U gain score (at developmental level 2).

A means of expressing the transfer effects in terms of a metric which, like that used for competencies, can adequately reflect the effects of merging one cluster of tasks with another cluster without requiring the analyst to re-estimate transfer effects during the aggregation process is required. Also, since the transfer effects due to similarity of tasks is being added to the gain effected by concatenating competencies, a compatible metric for the two is essential. Thus it was decided to express training transfer effects in terms of training hours saved as a consequence of a similarity expressable as a communality of each such task with a generic task that contains a set of general features included in a group of tasks.

The use of the concept of generic tasks could be avoided by requiring the analyst to make pair wise comparisons of all eligible tasks to estimate: (1) the overlap across each pair of tasks and (2) the uniqueness of each task (that part of the task that would provide training transfer effects to no other task in the set being evaluated. This approach would be more expensive of the analyst's time than the identification and use of generic tasks to accomplish a similar purpose. Also, the extension of pairwise comparisons to triples, quadruples, etc., with a mathematical deletion of overlap to achieve something comparable to set concatenation would require at least as many (and possibly more) assumptions about the distributions of the overlapping (duplicate) elements than is required in the proposed generic task approach.

The Proposed Approach. This approach calls for the analyst to identify common features across tasks and to organize these features, with the assistance of a Product 5 decision aid, into the format of a generic task. The number of hours required to accomplish mastery of the generic task is estimated by comparison with competencies in the data bank file possessing comparable descriptions and/or otherwise considered by the analyst to have similarities along relevant dimensions. This training transfer effect for a generic task expressed in training hours will be referred to as "TTH".

The TTH values are estimated for each generic task independent of the special characteristics of each task related to that generic task. Next, the analyst will consider each task on an individual basis and estimate both: (1) the maximum training transfer effect each generic task could have on that task--assuming all other tasks related to the generic task have been mastered, and (2) the training transfer effect that would be expected from the mastery of only one other task. The "other" task would be defined as one of an average degree of similarity--with respect to the features of the generic task held in common. These two effects will be estimated as percentages of the TTH associated with each generic task that could be saved under the two conditions (a maximum and the effect of only one other task) for each specific task. These two values will be referred to as P_{mgt} and P_{1gt} respectively for a specific generic-task and system task.

When there are several generic tasks that relate to a given task the analyst will have the option of estimating the percent of the required training time for a task that is unique to that task (Pu) and the percent (Pc) that is potentially made unnecessary as the consequence of the mastery of all

other tasks. Pu is analogous to the unique factor variance and Pc to the common factor variance in the factor analysis (Pu=1-Pc). The Pc for a task provides the upper limit of transfer effects from all sources on that particular task. In every case Pc P_{mgt} P_{1gt}.

<u>The Algorithm</u>. When a sufficient number of tasks which incorporate a particular generic task have been clustered into a job component, the transfer training effort for a specific generic task will be considered equal to P_{mgt} times "TTH" (see the first paragraph of this section). The effects of having just one pair of such similar tasks in a cluster will result in a smaller, proportional number of hours, computed as P_{1gt} times TTH.

The training effects for one task and one generic task when in a cluster of n similar tasks incorporating that generic task can be expressed by the simply stated algorithm provided below..

Iterate from i=1 to i=n to compute task multiplier of TTH for one generic task--this multiplier will be (multiplier)n at the conclusion of the following literature process:

(multiplier)o=0;
$(\text{multiplier})_i=(1-(\text{multiplier})_{i-1}/P_{mgt})\text{times } (P_{1gt})_i$

The same final result for $(\text{multiplier})_n$ will be obtained regardless of the order in which the n-1 other tasks are entered into the iterative process of the above algorithm. This multiplier can be seen to be equal to the value of P_{1gt} for the other task when there is only 1 pair of tasks in the cluster and will approach but not quite equal the value of P_{mgt} when the cluster size is large and/or the differences between P_{mgt} and P_{1gt} are small. An example of values for several examples of clusters are provided in Figure 15.

The algorithm above is based on the assumption that training transfer will behave as if the effect was due to overlapping elements which are spread evenly over the maximum area of overlap (represented by P_{mgt}). Each new task brought into a cluster brings in additional elements, some of which correspond to elements already counted as being held in common with at least one other task. Such duplicate elements must not be allowed to increase the size of the common area, but must instead be deleted from consideration. Only those new elements that fall into the as yet unexplained portion of the area identified by P_{mgt} should be allowed to increase the common area. This common area, expressed as a percentage of the training transfer effect of a specific generic task is the variable identified as $(\text{multiplier})_i$ in the above algorithm.

The job component training transfer score is computed as the sum of the task TTH scores for all constituant tasks. Each task score contributing to this sum may be computed as the smaller of two alternative values: (1) the sum of TTH scores across all generic tasks (for which an algorithm provided above) or (2) the largest TTH associated with a task times Pc.

<u>Training Transfer Effect as a Component of the S/U Measure</u>. When job components are merged the competency sets for the two constituant components are concatenated to form a new set with no duplicates for the merged job component. A similar concatenation operation is performed on D/Cs during the

Three Computational Examples
(For the Multiplier* That is Applied
To Training Hours for a Generic Task)

Example	i	Plgt	multiplier)i	Unique Proportion	Process**
1	0	-	0	-	-
1	1	.20	.20	1.0	(1-0/40).20+0
1	2	.15	.275	.5	(1-.20/.40).15+.20
1	3	.10	.30625	.3125	(1-.275/.40).10+.275
2	0	-	0	-	-
2	1	.10	.10	1.0	(1-0/.40).10+0
2	2	.15	.2125	.75	(1-.10/.40).15+.10
2	3	.20	.30625	.46875	(1-.2125/.40).20+.2125
3	0	-	0	-	-
3	1	.20	.20	1.0	(1-0/.40).20+0
3	2	.20	.30	.5	(1-.20/.40).20+.20
3	3	.20	.35	.25	(1-.30/.40).20+.30
3	4	.20	.3750	.125	(1-.35/.40).20+.35
3	5	.20	.3875	.0625	(1-.3750/.40).20+.3750

*The training transfer effect of a generic task on a task (as a result of being in a cluster of n tasks related to the generic task) is expressed as the number of training hours required for the generic task times (multiplier)n. The training transfer effect due to one generic task, for a cluster of n such tasks, is the sum of n such values.

**This process is expressed by the following iterative algorithm:

$(\text{multiplier})_o = 0$; $P_{mgt} = .40$;

$(\text{multiplier})_i = (1-(\text{multiplier})_{i-1}/P_{mgt})P_{1gt}\ (\text{multiplier})_{i-1}$

See text for definitions of P_{1gt} and P_{mgt}

FIGURE 15. Three Computational Examples

recomputation of technology complexity upon the merger of two job components. In contrast, the training transfer effect score for a candidate merger must be recomputed from task data; there is no concept of sets of generic tasks that can be concatenated to represent a set resulting from a merger. Nor can the training transfer effect scores of two constituant job components be summed to obtain the score resulting from a merger. Instead the scores for the tasks in the merged job component must be recomputed using the new value for n in to compute a value for (multiplier)n for each task and generic task in the new cluster. Fortunately this recomputation must be accomplished for only one row of the training transfer score matrix during each iteration, and for each task already in a cluster the value of $(\text{multiplier})_{n-1}$ is already known.

LEARNING DECAY RATE

The required number of training maintenance hours associated with a competency can be expressed as a product of how often (frequency) such training occurs and the number of training hours in each session (duration). Obviously duration and frequency can be traded off for any given competency. The shorter and less complete the training maintenance sessions the more frequently one can expect to need such a session. However, one can expect experts to agree to a considerable extent on differences in "best" durations and needed training frequencies under the condition of zero performance frequency--across a sample of the population of competencies.

The probable frequency with which maintenance training is needed for each competency is a function of the learning decay rate for that competency and the frequency with which the competency is practiced on the job (performance frequency). The latter is a function of which tasks are included in a job and, if frequency of performance is adequately estimated for the purpose of generating workload figures, is also available for inclusion in algorithms used to estimate training maintenance requirements. A greater performance frequency can compensate for a high learning decay rate, and a sufficiently high performance frequency can reduce the training frequency requirement to zero, irregardless of how high the training decay rate might be. The advantage in aggregating tasks with low performance frequency for a number of high cost competencies into a job composite already possessing a high performance frequency for those competencies is intuitively obvious. The proposed aggregation process for developmental level 3 is consistent with this intuition.

Data on learning decay would be obtained in terms of how long a soldier could go without a refresher training session under the condition of zero performance frequency. NCO,s at Schools and on-the-job locations could base such a judgement on actual experience with soldiers who have needed refresher training. Such expert judgements could be compared with learning decay findings in the literature. Their findings could could be used to define rules for estimating learning decay rate which, if shown to have construct validity, be used to generate learning decay rate estimates for Schools whose subject matter experts are not available.

IMPORTANCE WEIGHTING--ADVANTAGES AND DISADVANTAGES

Maximizing the Relationship of the S/U Measure to the Underlying Utility Function. If given the choice between placing a task in a cluster where its inclusion would add nothing to the training hours required to perform the job vs. placing it in an alternative cluster where the probability the new task can be performed well by all incumbents who can perform the other tasks well, Army managers would probably choose the latter. Fortunately the two criteria are very likely to be highly correlated, and the making of clustering decisions to maximize the first benefit will probably obtain most of the benefits obtainable from directly seeking the alternative goal. This correlation between these two criteria should be even higher if training hours associated with a competency were multiplied by a weight that reflected the relationship of the competency to the ability of a soldier to accomplish task objectives. Such weights are referred to in this report as "importance weights".

The Metric. It is important that training hours weighted by importance weights should still express training hours required to accomplish some objective. With the application of the weights, that objective changes from one of being proficient in a required competency to that of being able to accomplish task standards. The concept of the desirability of overtraining on the more essential competencies set at expense of undertraining on less essential competencies is introduced. Weights can be selected and applied which for a given task leave the sum of the weighted training hours for all competencies associated with a task equal to the unweighted sum.

The Analyst's Estimate. The analyst will be assisted by a decision aid in the grouping of competencies into importance categories for each task. The analyst would then indicate approximate percentages of overtraining and undertraining that best reflects his estimate of each categories' importance to the accomplishment of task objectives. The decision aid logic will compute weights, reflecting (as much as possible) the analyst's decisions, which will yield the same total number of training hours for the sum of weighted competencies as for the sum of unweighted competencies.

The Role of Importance Weights in Computing the S/U Measure. To compute the S/U measure for a newly merged job component, the weights for each competency will be averaged across tasks and then applied to each competency. This is algebraically equivalent to averaging the weighted competencies in the following manner:

Average weighted competence =
Sum from i to m (sum from j to $m_i(1/Lj)W_{ij}\ H_j$

--where n is the number of tasks in the cluster, and mi is the number of competencies in associated with the ith task, L_j is the number of tasks which require the jth competency, W_{ij} is the importance weight for the jth competency in the ith task and H_j is the number of training hours associated with the jth competency. If all W_{ij} are equal to one this algorithm would be equivalent to concatenating the sets of competencies associated with each task and then summing the training hours associated with the concatenated set.

ACCEPTABILITY, USABIITY AND USER WORKLOAD

By assigning selected functions of Product Five to the analyst, a minimum cost product containing only four modules will be designed. This minimum cost system, requires the analyst to designate task membership in jobs (as part of the last module). The following four modules would comprise this system: (1) Task Identification, (2) Task Data Generation, (3) WorkLoad Data Generation, and (4) Manpower and Personnel Requirements. In this system, the first module would require the analyst to select the baseline system(s) with no more assistance than is provided by MIST but would otherwise remain as in the complete Product Five system. The second module would involve a greatly reduced effort by the analyst; the third module would require more analyst effort; and the last module would require much more effort and more difficult analyst judgements.

With additional cost, additional capabilities could be successively added to this minimum Product Five. A hierarchy of such product designs, each more costly than the preceeding one of lesser complexity and capability, could be provided to meet a variety of cost figures in accordance with the "design to cost" philosophy.

A HIERARCHY OF DESIGN

The first step upward from the minimum cost system should include the addition of a combined duty module and position generation module consisting of the 0/1 constraint matrix and supporting decision aids. No data bank would be required for this economical design. The merging of job component pairs could be accomplished by considering only connectivity and the 0/1 constraints on task mergers, tested each time by a workload threshold set by the analyst. The effort required of the analyst in the task data generation module would increase since he must create the 0/1 matrix from his information regarding the system, and any other relevant information pertaining to the proposed implementation.

The second step upward, to obtain a definite increase in capability at minimum cost, should include the consideration of the S/U clustering algorithm in the task aggregation model for both a duty module generation module and a duty position generation module. Only one data bank file, the competency file, would be added as part of this design increment.

The third step upward should include the addition of the other three data banks and the other three modules. The system would then include all the modules at the S/U development of level 1.

The fourth and fifth steps upward in cost and capability should correspond to S/U developmental levels 2 and 3 respectively.

THE EXPANDABILITY CAPABILITY

It was noted earlier that the cost of adding additional features later was not much more than the cost of providing these features initially in the product; this was said with specific reference to the features required to expand from developmental level 1 to developmental 2 and 3. This is partly

true because the data bank shell and most of the user interface software would already be in place at the completion of level 1 development. However, for the most part, this expandability capability must be deliberately designed into the product as proposed by the Perceptronics and HSI research team.

Not so much of the overall structure of Product Five development level 1 (step 3 in the hierarchy described above) is present in the minimum cost or step 1 design. The overall structure of the product as present in the 3rd, 4th, and 5th step designs first becomes recognizable in the 2nd step design.

A design-to-cost strategy that provided for the construction of a product at either the 2nd or 3rd steps of cost and capability is a practical alternative that should be considered. The cost and benefits that could be expected from each successive expansion could then be determined with greater certainty.

DETERMINATION OF SCHOOL AND MOS BOUNDARIES

Army personnel managers resist the proliferation of MOS's and of special assignment categories within MOS that might come about if the MOS structure were altered each time it appears that a newly introduced system has different requirements for: (1) soldier characteristics, (2) training, or (3) career progression than the most similar existing MOS. Similarly, Army schools hesitate to introduce new courses when they suspect that a small addition to an existing course and/or a heavy reliance on on-the-job training can meet minimum requirements. Thus the creation of jobs that cut across MOS and/or school boundaries run more than just the risk that the cost of providing the new MOS and new school courses will be charged to the development system. There is a real risk that the new job will be laid on a Procrustian bed and made to fit the existing system, regardless of the cost to system performance.

The Manpower and Personnel Requirements as estimated by Product Five will be more valid if the jobs used for making estimates of workload and number of required jobs are very close to the duty positions that will eventually be placed on TO&E's and TDA's for the fielding of the system.

One must carefully consider the need for a model to detect tasks that either: (1) lie on MOS or school boundaries or (2) lie on the opposite side of such a boundary as compared to other relevant tasks--tasks that the aggregation model will place in the same job when the boundary consideration option is not used. If this detection can be readily accomplished by the analyst using existing resources outside of Product Five, the analyst can also be presumed capable of assigning boundary violation scores to each task. If the analyst has these capabilities, the cost of creating a data bank file and a decision model can be avoided. The option for the data bank file and decision model has been included in the proposed design based on the belief that many analysts will not in themselves be sufficiently expert in Army personnel and training systems to allow them to make the independent judgements otherwise required.

The content of the MOS and School Boundaries file will be drawn from the content of the other data bank files, and the descriptors will include those used for the competency file, the Baseline Systems file, and the D/C file.

The difference between those other data bank files and this data bank file lies in its additional descriptors (e.g., D/Cs and competencies) and its structure.

The MOS and School Boundary File will have relatively small records containing primarily MOS and School identification data but will have more descriptors and multiple links between descriptors and the file records. A file search by the decision model will yield the distribution of descriptor links to each MOS and school relevant to the set of descriptors entered from the task data working file.

The distribution of descriptor links to each MOS and school will be analyzed by the decision model on a task-by-task basis to determine whether a single primary membership in a MOS or school domain exists. Where such a primary membership exists, links to other domains that duplicate the descriptors linked to the primary domain will be deleted and the remaining links analyzed to see if a significant linkage to other domains remains. These "significant" links will then be scored to yield a boundary violation score for the task.

Tasks for which two or more primary memberships in MOS or school domains exist will be analyzed separately with respect to each domain. The computation of a boundary violation score requires the selection of one of those multiple domains as relevant to the cluster to which the task has been assigned; all non-duplicative links to other domains are counted as boundary violations.

DESIGN AND DEVELOPMENT OF DATA BASE FILES

The data base files utilized in the proposed Product Five have been included because their presence will provide the following benefits:

(1) The analyst can readily draw upon Army doctrine and the judgements of a variety of experts without having to select, locate and prevail upon such experts to render judgements during the process of each analysis.

(2) The quality of this information acquired systematically for the data bank should exceed the quality of the information the analyst could obtain through his own efforts.

(3) The cost of obtaining the information for the data banks will be less than the cost of having a number of analysts obtaining the required information, on their own, to analyze all relevant systems over a three year period of time.

(4) Information obtainable from a data bank file reduces the burden on the analyst of providing input to analysis models.

(5) The availability of information in the appropriate format makes an objective and systematic analysis possible, with complete documentation and repeatability of that analysis assured.

The data base consists of four special purpose information files and a shell which assures that those files are available to the models and decision aids that require access to these files. The shell provides for direct access to these files, and provides for direct access by the analyst for content additions, direct queries, and other purposes. The shell will also provide such interfaces to the user as menus and helps in the direct use of the data bank.

I/O RELATIONSHIPS WITH PRODUCT SIX

Jobs, in terms of their constituent tasks, and the workload for those jobs for the system(s) being evaluated will be provided as output to a working file that can easily be used as input to Product Six. The number of jobs associated with specified system deployment figures, and the total Army wide manpower implication, by job, will also be recorded.

As useful for Product Six analyses or for reference by the analyst in establishing Product Six options and parameters, duty modules can be provided on the working file for Product Six use. As with jobs, the duty modules are identified in terms of their constituent tasks and by the jobs of which they are a component. Workload, and criterion variable values (S/U measure, technology complexity score, and both School and MOS membership information and School and MOS boundary violation scores) can also be provided. All information in both the working files (particularly the task 0/1 constraint matrix), and the data bank files of Product Five would be useful to the analyst for both setting up Product Six and for interpreting Product Six results.

Product Five Iterations in Response to Product Six Results. Soldier characteristics data on the jobs produced in Product Five may indicate where further job engineering should be accomplished (e.g., to reduce the number of jobs with a high cognitive loading). To the extent that such Product Six results can be attributed to specific tasks, these high driver tasks can be identified as kernels of duty modules that will be more homogeneous with respect to required soldier characteristics. This can be accomplished through the modification of the 0/1 constraint matrix and then proceeding once more through the aggregation process.

It should be noted that the cognitive loading of tasks in a duty module could be high although the technology complexity score is relatively low--if the technology requirement is highly focuses with only one of a very few high technologies required. Product Five provides the means of controlling the span of technology requirements but requires feedback from Product Six to control the level of the requirement.

Use of Product Six cognitive loading data as a fourth criteria variable: it would be relatively easy to design product Five to provide the analyst the option of setting upper and lower threshold values on a Cognitive Loading Variable. The computed values of the Cognitive Loading Variable for each task to be compared to the thresholds would be obtainable from Product Six. However, such a variable would have to be used in a different fashion than the other three criterion variables. The other three are used with a logic that tests the upper limit permissable for those criterion variables in a cluster.

The lower limit for cognitive loading values would be at least as important in testing for acceptability of two job components for inclusion in a merged component. Thus an acceptable range, rather than a single threshold value, would have to be tested to determine whether a merger is consistent with the job engineering goal of reducing the number of jobs having a high cognitive loading.

Use of Product Six cognitive loading data as task similarity measures: Task Cognitive Loading (TCL) values from Product Six could be substituted for task S/U measure values for use in the aggregation process of the Product Five clustering algorithm. A more traditional clustering approach would then become appropriate. The goal of the clustering process would become one of maximizing the homogeneity of the tasks in a job component with respect to TCL. A process analogous to a discriminant analysis--in which the within cluster variance of TCL values are maximized and the between cluster variance is minimized--all within the constraints of the 0/1 constraint matrix, would meet the engineering objective of reducing the number of jobs with a high cognitive loading.

The provision of a capability of clustering on TCL, as described above, is not included in the costing for this concept paper. This is a capability that could be added after the completion of Product Six.

THE ZERO LEVEL OF S/U DEVELOPMENT--DEVELOPMENT LEVEL ZERO

Proceeding without the use of a S/U measure and when the 0/1 constraint matrix leaves no room for further clustering was addressed. It is believed that the tasks for some systems, particularly the operator tasks, will be so constrained as to preclude the necessity of computing S/U measures. Other systems may have jobs so well defined by predetermined doctrine that most tasks will be placed immediately in strawman jobs with only a very few tasks remaining unassigned. In such cases the analyst may still wish to evaluate jobs and assigned tasks in terms of the three criterion variables--but completely bypassing the aggregation process that is based on the S/U measure.

For the strawman option, the analyst may have predefined jobs which <u>must</u> contain a number of specified tasks. These tasks provide a kernel for strawman jobs which can then be compared with "loose" tasks. Zeros can be placed in appropriate cells of the 0/1 constraint matrix to assure that two kernels will <u>not</u> be merged with each other. The analyst may choose to assign the "loose" tasks by reference to the criterion variables, again without recourse to the S/U measures.

The optional capability of clustering tasks from the 0/1 constraint matrix and clustering to maximize connectivity was also addressed. In addition to expressing the permissibility of merging each pair of tasks, the 0/1 constraint matrix contains information regarding the extent to which future aggregation options are foreclosed if two tasks are merged. For example, two tasks for which a merger is permissible may result in a two-task job component which can be merged with no other tasks--although each could be merged with almost half of the other tasks. A connectivity index for this pair would be very low and would indicate the undesirability of making such a merger. A measure of connectivity for each pair provides a good estimate of

how many other tasks remain as potential members of a cluster initiated by merging that pair of tasks. If the optimal pair for merger is selected on the basis of its high connectivity index, one must also verify that the selected pair has a one at the juncture of those two tasks in the 0/1 constraint matrix. In short, connectivity, computed entirely form the 0/1 constraint matrix, may be treated as the objective function, but the constraints recorded in the 0/1 matrix must also be obeyed in selecting pairs for merger.

Computing a measure of connectivity for the 0/1 constraint matrix will be referred to as the matrix M. The squaring of this matrix, producing M2, provides a matrix in which the element in the ith row and jth column provides the number of tasks that could be contained in a merged task consisting of the ith and jth tasks. This powering of M provides us with a good measure of the connectivity available after each potential merger of task pairs.

It is recommended that Product Five will have an optional capability of clustering job components to maximize connectivity. Even when the analyst chooses to use the aggregation approach that utilizes the S/U measure, he may choose to have the results of M2 displayed to him, to indicate to him the extent future clustering options are being foreclosed by accepting the merger of the pair yielding the best S/U measure.

The clustering process based solely on the maximization of connectivity while complying with the constraint matrix as follows:

(1) Compute M^2, retain M
(2) Select the largest cell value in M^2
(3) If equivalent cell in M is a one (otherwise delete cell value and repeat step 2, then do a logical add of the two rows and columns corresponding to the selected cell (the order of M is thus reduced by one).
(4) Defining the row of M corresponding to the newly merged tasks as V, compute the follow:

$$V_2=V_1M$$

(5) Select the cell with the largest connectivity value considering the cells in V2 and all cells in M2 except those in the rows ad columns corresponding to the cell previously selected.
(6) Repeat step 3 and set 4
(7) Repeat step 5 except that these are now two V2 vectors to consider
(8) continue interation until
    (a) Connectivity value in a V2 vector is larger than any connectivity value in M2, or
    (b) The order of M is reduced to 2.
(9) Select largest connectivity value in the set of V2 vectors, and select the corresponding task pair for merger.

TRAINING OF USERS

This section presents several technical ideas that are viewed as logical outgrowths of the "user-friendly" front-end for the conceptualized system.

The enhancements presented herein focus on taking advantage of the behavior of both experienced and naive users as they interact with the "user friendly" interface to the data base. When a user addresses a particular logistics or forecasting problem using the system, he will have some specific goal in mind. He will then try to use the system in a number of different ways to achieve that goal. The overall concept here is to capture the approaches that the user employs in software, and to build a "library" of user "protocols" (ways of addressing a problem) that may aid a subsequent user in solving a similar (but perhaps not identical) problem in the future. In this way, the system is expanded so as to become a more useful and more "friendly" tool in meeting the goal for embedded training in the forecasting arena in general. We believe that much more advantage can be taken of the computer in-the-loop as an aiding device for users of all experience levels in achieving the ultimate goal of accurate and rapid forecasting.

It is apparent, from the nature of military software systems, that the burden of operating the system and making it do what the user wants it to do is on the user himself. This is true especially for systems developed without due consideration of the user's behavior patterns, his natural tendencies when performing a task, of patterns, or his capability to absorb the meaning of the plethora of different functions and commands inherent in most software packages. The solution to this problem has been to spend enough time at the "front end" of the system development cycles to determine exactly what the user needs from the system, as well as what the user brings with him to the job (e.g., knowledge, experience, tendencies, etc.). The result of those development efforts that have dedicated significant amounts of time to front end planning has been a better user interface for the products of those efforts, so that, in many cases, the user can get the job done appropriately. However, even with a fairly well-designed user interface, many systems still require modules or components that supply additional aid to the user. Most common of these "aids" are help modes, manuals, walk-through tutorials, and often costly and time-consuming training courses or curricula. This is especially true in the military where it is rare to see a software-based system developed that does not require extensive training.

PROTOCOL FOLLOWING

The concept of protocol following involves tracking, in software, what a user does as he interacts with a computer-based system. In the current application it would be very valuable for the system to allow the user to go back (after task performance) and investigate the procedures, interactions, or activities he engaged in that produced the resulting forecast, whether that result was desirable or not. If the designer wanted to include that capability in the system, he would track the user's keypresses, screens accessed, files and fields viewed and selected, and other components of the user's "protocol", and store them in the system for access and review later. Although a certain amount of programming and user interface design (specifically for later viewing and understanding the protocol) would be required to provide this capability, the concept is rather simple and straightforward, and is certainly a workable one.

QUASI-EXPERT SYSTEM

Although it enjoys a notable reputation, the concept of an expert system appears to be as variable as the range of individuals claiming to have built one. For purposes of this paper, we refer to the component of the system we are proposing to implement as a "quasi" expert system. What is meant by this is the ability of the system to generate, upon user demand, several alternative ways to go about solving a problem. Clearly, the alternatives would have to be matched against general categories of problems. Thus, a taxonomy of problem types would have to be generated based on what we know about operations. The alternatives developed to solve these types of problems would be based on the protocols that could be captured while "experts" are using the current system and from elicitation from experts of the optimal strategies for addressing and solving a wider range of problems.

The alternative approaches mentioned above can be considered "expert models" of system use that have been employed previously with positive results. In general, it is clear from the research on human performance that the best and easiest way to increase on the probability that an individual will perform a task appropriately is to provide that individual with a model of a similar task previously performed successfully by someone else (or even by himself). The model, in essence, serves as a reference for the user that is aimed at improving productivity as measured by both speed and accuracy of performance (Asiala, 1985).

ADAPTIVE TRAINING

Of the many types of training approaches in the literature, adaptive training is of the most productive. By "adaptive" is meant training that conforms to the trainee's level of performance at any given time. For example, if a trainer were training a student to fly a plane, the training would present a specific problem related to flight and would observe the trainee's performance. If the trainee failed to perform appropriately, a good trainer would attempt to restructure the problem in a simpler form, perhaps omitting a more difficult component temporarily from the training scenario. If the trainee's performance improved, the trainer would then increase the difficulty of the problem (perhaps by reintroducing the difficult component he temporarily removed) and observe the trainee's performance. In this way, the amount of information presented to the trainee at any given time, or the difficulty of the problem the trainee is called upon to address, is under the trainer's control, and is "adapted" to the trainee's current level of performance.

LOGICAL INTEGRATION OF THE CONCEPTS

We believe, then, that protocol software should be developed that allows a user's behavior to be tracked throughout various interactive sessions with the system. We further believe that both novice and expert users should be interviewed and data collected on the manner in which a wide range of problems might be handled, given access to particular data. Moreover, investigation and evaluation of those protocols that have been obtained from various system users, may allow selection of several protocols as models for operating the system with particular outcomes are desired.

Given the above information, it is possible to structure the range of user problems into categories that differ with regard to the level of difficulty they present to tie them, both conceptually and in the actual software, to the appropriate models of user problem solving that we have developed. This would form the basis for an "adaptive training" mode of system operation, wherein a user would start at a particular level of system operation (specific to the task he had to perform) and would attempt to solve the problem. If the user failed to solve the problem at that level, the system would automatically present an alternative model of lesser difficulty to the user, training the user throughout the session to a level of acceptable performance for a task of that difficulty. Once the user has mastered performance for that level of difficulty of the problem (and the associated model)the level of difficultly would increase, and so on. The result of this adaptive training would be to adjust the training parameters to the user.

SUMMARY OF TRAINING THE USER

System documentation will be used for the training of users. This documentation will be three dimensional, consisting of software specification, software functional description, and a genuinely useful training and user's guide.

Software Specifications and Documentation. Software routines and subroutines, as well as all special-function software modules will be detailed and explained in a software specifications document, largely before any of the actual code is written. This will be reviewed by the software engineers (along with the human factors engineers) and all questions as to system software functions and training issues will be addressed early on in the process of writing code.

In addition, all system software will be well-documented, as part of the coding process. This refers to actually writing into the code (as comment or explanation lines) what each module and routine of the software is designed to do. This is critical so that if, for any reason, the original software programmer that wrote the code is unavailable, another programmer will be able to learn the code and the entire program, and make whatever additions or modifications to the code are necessary, accurately and without delay.

Software Functional Description. The functional description of the software for Product Five will be available for training system functional issues.

Training and User's Guide. The Training and User's guide documentation will be used during training sessions.

This user's guide will be one that follows the sequence of operations inherent in the system itself. Therefore, it is advantageous to present the information contained in the user's guide in a well structured, well-indexed fashion that follows the general procedures of the system itself. Further, since the system has been designed with regard to on-screen instructions, prompts, error messages (that inform the user not only what error was committed but what he must do to correct the error), the user's guide is a reference that the user may access when he requires detailed information on a particular function, rather than a "how to use the system" tool. Idealy, the Product Six system is one whose operation is largely self evident. That is,

the user of this properly "human factored" system will be able to "walk into" the system, guided only by the on-screen instructions and prompts provided. Although some systems are of such complexity that a manual is indeed necessary, the approach to the development of the Product Six system is one wherein on-screen (dynamic) information regarding its operation has been maximized, and static (off-screen) information regarding its operation has been minimized.

INSTITUTIONALIZATION

ACCEPTANCE AND IMPLEMENTATION

MPT Product. The two most critical aspects of this ARI project are an understanding of its unique importance to the U.S. Army, and the necessity of taking the proper steps to ensure that the Army will accept and implement its results.

In many previous cases of advanced weapon system development, insufficient attention has been paid to the human component of the system in the early conceptual stages, and as a result the systems have encountered serious problems during the development and fielding stages. In the case of the MANPRINT effort, however, this does not appear to be the case. Considerable attention is being given at top planning levels to the human component and to the means available for integrating MANPRINT data into the design and development of new and complex systems.

System Transfer. In an article in Computer Decisions by Martin Lasden (1981), a passage from Machiavelli's The Prince is cited regarding the subject of change:

> "There is nothing more difficult to arrange, more doubtful of success, and more dangerous to carry through than initiating changes. The innovator makes enemies of those who prospered under the old order, and only lukewarm support is forthcoming from those who prosper under the new. Their support is lukewarm, partly because men are generally incredulous, never really trusting new things unless they have tested them by experience. In consequence, whenever those who oppose the changes can do so, they attack vigorously, and the defense made by the others is ineffective. So, both the innovator and his friends are endangered together."

This brief passage might very well summarize the perils of technology transfer. But if we study the passage for a moment, a number of ideas emerge regarding how to introduce a system such as Product Five into the "field".

The first has to do with pacifying "those who prosper under the old [non-computer-based system] order." Incentives must be implemented that will make them at least eager to experiment with the new system. (Furthermore, since the system has been designed with the aid of a solid requirements analysis they will not have to restructure what they do to use the system;

instead, the system will be able to help them improve their job performance.) The incentives must be explicitly job related, and bureaucratically sanctioned. The job relatedness criterion has been satisfied by a judiciously implemented requirements analysis. If a requirements analysis is not (or is badly) performed, there will be a perceived and real disconnect between what the system and target user do. Under these circumstances, some users will accept computer-based systems, display them prominently in their offices, seldom actually use them, and then eventually transfer out of their office on the crest of a reputation for innovativeness and vision.

Another solution to the job-relatedness problem is to consider the newly developed participatory approach to computer systems design (Mumford and Henshall, 1979). The impetus for the development of the approach has been summed up nicely by one Qulaity of Working Life Institute consultant: "no one has the right to design a work system for someone else.....the role of the expert should be to help the worker design his own work system" (Lasden, 1981).

Finally, the transfer strategy should involve some trial field applications before the final version is released and distributed en masse to prospective users (if that is the plan). This will provide some valuable user feedback to the designers so that they can make any necessary adjustments.

<u>Implementation of Solution Approach</u>. We will encounter some obstacles in the implementation of the solutions outlined above. From our experience with programs of this type, three major obstacles are virtually certain. One is that the timing of major technology transfer steps is frequently critical, and is usually difficult to adjust to rapidly if these steps have not been anticipated. Two is personnel turbulence within the military structure, so that by the time a person is indoctrinated in the importance of the project, he or she has moved on. Three is that the resources necessary to effect transfer are usually not planned for when the R&D project is staffed, scheduled, and funded, so that they can not be afforded when they are needed.

To ensure our close attention to these important issues involved in technology transfer -- including the identified problems, implementation strategies, and obstacles -- we will address problems of technology transfer by adopting a discipline of transfer planning and implementation previously found to be successful in numerous efforts. This task will feature early and continuing user participation in the program to guarantee the support of the ultimate beneficiaries of the Product Five concept, it will insure that project resources are there when they are needed, and it will promote the long term persistence, which is necessary if the transfer plan is to be successfully executed.

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